STREET PAVEMENTS

AND

PAVING MATERIALS.

A MANUAL OF CITY PAVEMENTS: THE METHODS AND MATERIALS OF THEIR CONSTRUCTION.

FOR THE USE OF STUDENTS, ENGINEERS, AND CITY OFFICIALS.

BY

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PREFACE TO SECOND EDITION.

SINCE this work was originally given to the public a number of new pavements have been introduced and the methods of constructing the old have been so modified as to render necessary a pretty complete revision of certain chapters and the addition of a new chapter on concrete pavements. No attempt has been made to deal with road construction, as that would require a a volume by itself.

A chapter has been added called "The Protection of Pavements." This is a matter that must be given serious attention in this country, where it seems necessary to have a great deal of subsurface street construction. The author hopes that this chapter will be of benefit to cities that are about to take this matter under consideration.

In making this revision the author is indebted to many city officials and others who have kindly furnished him with desired information, and he takes this opportunity to thank them for the same. Special thanks, however, must be given to Dr. Felix Kleeberg, Chief Chemist of the Bureau of Highways, Borough of Manhattan, New York City, and Dr. Clifford Richardson, of the New York Testing Laboratory, for information regarding asphalt and methods of testing same; Mr. Carl F. Adam for a description of the manufacture of oil asphalt; Mr. Will P. Blair for his description of the manufacture of paving brick; and Mr. Geo. S. Webster, Chief Engineer, Bureau of Surveys, Philadelphia, and Mr. Morton L. Fouquet, Engineer of the Bureau of Substructures, Borough of Brooklyn, New York City, for information regarding the work of their bureaus in their respective cities.

G. W. T.

BROOKLYN, N. Y., September, 1912.

PREFACE TO FIRST EDITION.

In presenting this work to the public the author does so in the hope that it will answer some questions that have been presented to him during the past, and whose solution was only obtained by actual experience.

Fifteen years ago there was probably less literature extant upon the subject of street pavements than upon any other one branch of the engineering profession. Such great advance has been made in pavement construction during that period that works of that day are practically useless at the present time, except as records of what has been done.

An active participation in the construction of municipal public works, particularly in pavements, during the past twenty years has seemed to justify the author in producing this book in order to show not only what is being done at the present time in pavement construction, but also the evolution of the modern city street from the rude roadways of centuries ago.

Much time has been spent in historical research, and in Chapter I will be found a collection of facts that makes a fairly well-connected history of pavements and roads.

It would be useless to enumerate all the works that have been consulted in the preparation of this volume, as they include encyclopedias, dictionaries, scientific works, technical journals, society and official reports, special reports of consular agents and official committees, magazines, popular publications, and in fact all literature that would furnish information on the subject. Unreliable statements have either been rejected or given for what they were worth.

The author is greatly indebted to consular agents and city of-

ficials, who have cheerfully furnished him with valuable and interesting facts.

Much of the information contained in the chapter on Stone has been obtained from different geologies, and the reports of the U. S. and State Geological Surveys. The entire chapter has been revised by Professor Leslie A. Lee of Bowdoin College, Brunswick, Me., who has thus placed the author under great obligations to him.

The chapter on Asphalt has been prepared from the writings of Clifford Richardson, Professor S. F. Peckham, and others, as well as from personal investigations, trade publications, etc.

Much of the information relative to the payments for pavements by street-car companies was obtained from a report made to the Massachusetts Legislature by a committee appointed to investigate the relations between cities and towns and street-railway companies.

The main idea of the work has been to have it practical, so that an engineer unacquainted with the subject could obtain sufficient information to prepare specifications for, and intelligently supervise the construction of, pavements.

G. W. T.

BROOKLYN, N. Y., Sept. 1, 1900.

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STREET PAVEMENTS AND PAVING MATERIALS.

CHAPTER I.

THE HISTORY AND DEVELOPMENT OF PAVEMENTS.

PRIMEVAL man had no pavements nor any use for them. His wants were few and easily satisfied. He knew of nothing outside of his own range of vision. Knowing but little, his desires were few and in almost every instance could be satisfied by the fruits of the soil or the results of the chase.

But this could not continue; as the race increased and scattered over the then known world the different divisions settled down into communities or became nomadic tribes. Different localities produced different articles, and in their wanderings and communications with each other they became acquainted with their different products, and the spirit of interchange and commerce sprung up among them. Feelings of rivalry arose, producing wars, and there is no doubt that the commercial and warlike interests were most powerful in promoting exchanges between tribes and later between nations.

At first tracks were established across the country, but as time went on these tracks grew to be paths, and the paths roads, and the roads developed into our modern highways, paved streets, and magnificent system of railroads. All of this, however, consumed a vast amount of time, and many centuries elapsed after the building of the first road before much similar work was undertaken or the modern boulevard completed. While war-chariots are mentioned in

history as existing at as early a period as war itself, commercial commodities were transported in ancient times almost entirely on beasts of burden. Hence the slow growth for a long time of the demand for roads.

All records of work done in the early life of the human race are indefinite, and much that ought to be history and founded upon fact is only conjecture.

It is said that a little to the east of the Great Pyramid remains of a stone causeway a mile long have been discovered. This is supposed to be a portion of a road built by Pharaoh for the purpose of conveying stone or other material across the sand for the construction of the pyramid. As this pyramid is generally considered to have been built in the fourth dynasty, or about 4000 B.C., it is undoubtedly, if authentic, the oldest road on record.

Another ancient boulevard is mentioned by historians which must have been built soon after, as these times are now considered. The city of Memphis is said to have been connected with the pyramids by a broad roadway, two leagues long, having a paved and well-kept driveway lined on both sides with temples, mausoleums, porticoes, monuments, statues, etc. In fact, according to descriptions it must have been the modern boulevard with all the accessories that the times and unlimited wealth would allow.

The Carthaginians, however, are generally given the credit of being the first people to construct and maintain a general system of roads. This African city had sprung up about 600 B.C. and by its growth and enterprise became a rival of the Roman Empire across the Mediterranean. Rome endured this rivalry for a time, but at last she issued that famous edict, *Carthago delenda est*, which resulted in the invasion of Africa and the destruction of Carthage B.C. 146.

The Romans without doubt appreciated the benefit of improved highways for the rapid mobilization of troops, for they immediately took up the practice of the Carthaginians, and road-building was always one of the features of their subsequent conquests. It is claimed that in Great Britain alone they constructed 2500 miles of roads.

The Appian Way was built by Appius Claudius about 300 B.C., and the Flaminian Way some years later. These roads were prac-

tically examples of solid masonry laid in cement mortar and sometimes several feet thick.

A traveller in one case reports having crawled entirely across a road under the pavement where the earth had been washed away and the masonry had been self-supporting. Such roads lasted a long time. The Appian Way was said to have been in good repair eight hundred years after it was built. But it must be remembered that the traffic it sustained was of such a nature and amount as to produce a very slight abrasion on the roadway. The stone used was irregular in size and shape, but laid in such a manner as to make a solid roadbed impervious to water.

Prof. John Beekman of the University of Göttingen states in his "History of Inventions and Discoveries" that the streets of Thebes were regularly cleaned, and that the Talmud says the streets of Jerusalem were swept every day, and accordingly concludes that they must have been paved.

A consular report from Palestine states that the pavements of Jerusalem laid by the Romans over two thousand years ago are still in fair preservation, but adds: "They are indeed hidden from sight, and are many feet beneath the rubbish of the city." It is easy to understand how a stone pavement might last centuries under such conditions.

Mexico and Peru, although not countries where much transportation was ever carried on by vehicles, built in ancient times many foot-roads of great excellence; those of Peru alone extended for more than a thousand leagues.

In the special consular reports it is stated that more than one thousand years before Columbus discovered the New World, the province and also the city of Genoa boasted of fine roads and streets.

In France all travelling was done on horseback until the latter part of the sixteenth century. In 1508 Louis XII. appointed officers to inspect and report upon the condition of all roads; to repair those under the care of the king, and to enforce the repair of the others by the proper authorities. Other rulers followed his example, but little good was accomplished, as these officers were often appointed and almost immediately discharged so as to create vacancies which might be filled upon the payment of a certain fee,

thereby creating a considerable revenue by the sale of appointments. This fact would seem to show that corruption existed in the carrying out of public work in ancient as well as in modern times.

In the latter part of the sixteenth century Henry IV. appointed a "Great Waywarden of France." This is probably the earliest record of the appointment of a public official with a specified title to have systematic supervision over the public roads.

These different actions, however, do not seem to have accomplished much, as it is recorded that as late as 1789 the country roads of France were generally in a state of nature or worse.

It is, however, stated that in 1556 a stone road was built from Paris to Orleans, the portion improved being 15 feet, although the entire width was 54 feet.

The first highway constructed in Spain, after the Roman régime, was built by Fernando VI. in 1749 from Santander to Reinoso, the labor being performed by soldiers. In 1761 regulations were made for the classification, construction, and repair of highways in general, but no definite results were obtained. In 1794 the matter was delegated to a special bureau of the government, but with no better success. And it was not till 1834, when an engineering school was established, graduating its first class in 1839, that any real good was accomplished. From that time roads were built according to the condition of the public treasury.

The first Highway Act for the improvement of roads in England was passed in 1555.

The above facts relate to roads rather than pavements proper, and it is interesting to note to what size European cities grew before any particular attention was given to street pavements, and how many years it required to arrive at any satisfactory results. Alexander Dumas said after a visit to Russia, in answer to a question as to how he found the streets and roads, that he had scarcely seen any, inasmuch as during the winter season they were covered with snow, and during the summer they were in process of repair.

The streets of Rome were paved in the fourth and fifth centuries after the founding of the city.

The first pavements in Paris were laid during the reign of

Philip Augustus about 1184, the square of the Châtelet and the streets of St. Antoine, St. Jacques, St. Honoré, and St. Denis being the first improved. The population of Paris at that time must have been little less than 200,000.

Cordova, Spain, although a small place, is said to have had paved streets in 850.

The Strand, London, was ordered paved by act of Parliament in the fourteenth century, and streets outside of the city in the sixteenth, although it is said that the first regular pavements were laid in 1533, when the city had a population of 150,000. Holborn had some pavements in 1417. Square granite blocks were introduced by acts of Parliament for Westminster in 1761, and for London generally in 1766.

When the Forum Trajanum was cleaned by the French in 1813, the old Roman pavements were found on an average of 12 feet below the then surface. The stones in these old pavements were polyangular in shape, containing from 4 to 5 square feet and 12 to 14 inches deep, laid with close joints. More modern blocks in Rome were about 2 cubes long, and on being set up endwise had an area of 10 square inches. This would give a block about 7 inches long, 3½ inches deep, and 3½ inches wide. They were set on 12 inches of cement concrete.

A recent novelist, speaking of London in 1516, says: "There were great mud-holes where one sank ankle-deep, for no one paved their streets at that time; strangely enough preferring to pay the sixpence fine per square yard for leaving it undone." How often this fine was imposed was not stated.

Speaking of London in 1685, Lord Macaulay says: "The pavement was detestable; all foreigners cried shame upon it. The drainage was so bad that in rainy weather the gutters soon became torrents."

Walter Besant in his "History of London" states that in the Elizabethan period carts only were allowed on the street, and their number was restricted to 420. Merchandise was carried on pack-horses. Also: "In the streets the roads were paved with round pebbles—they were cobbled; the footway was protected by posts placed at intervals; the paving-stones, which only existed in the principal streets, before 1766 were small and badly laid; after a

shower they splashed up mud and water when one stepped upon them."

In a pamphlet written by a Colonel Macirone of London in 1826, when the city had a population of 1,400,000, the author says: "Florence, Sienna, Milan, and other Italian cities have pavements with especially prepared wheel-tracks. These tracks are three feet in width, made of large and particularly well-laid stones. They are about four feet apart, and the space between paved with smaller stones." He further states that these pavements, as well as those of Rome last mentioned, are the best that he has ever seen, but that they would be too expensive for London. Also: "There is no species of pavement that I have ever seen or heard of to the application of which to the streets of London there would not be many and great objections. . . . However true it may be that an observant traveller cannot fail of being struck with admiration at the excellence of the turnpikes and other roads throughout this country, he must at the same time be very much surprised at the badness of the carriage-pavements, even of the principal streets of this metropolis."

These were the observations of an engineer who had travelled and examined the European pavements of that time, and they ought to express fairly their condition.

This was about the time of Macadam and Telford, and soon after this considerable broken-stone pavements were laid in London.

A pavement consisting of broad, smooth, well-jointed blocks of granite for wheel-tracks, with pitching between for horses, was laid in Commercial Road, London, in 1825.

In 1839 there were 1100 square yards of wood pavement in London, which in 1842 had increased to 60,000, when, according to a statement made in the City Council by an alderman during a controversy as to the relative merits of wood and stone pavements, there were 600,000 square yards of the latter, probably nearly if not all macadam. These two items without doubt represented the total amount of pavements in a city of nearly 2,000,000 people.

In 1825 Telford recommended the use of stone blocks $4\frac{1}{2}$ to $7\frac{1}{2}$ inches in size for street use; and 3×9 inches granite sets were laid on Blackfriars Bridge with mortar joints in 1840. This was probably the first attempt at a modern stone pavement. Rock

asphalt was laid in London on Threadneedle Street in 1869, and in 1873 there were 60,802 square yards or 4.25 miles of this pavement, and 12,238 square yards of wood, in the city. This would indicate that wood, as first laid, was discontinued, and was not used again till laid in its improved form.

Concrete was first used in London as a base for pavements in 1872, and the custom was general in 1875.

In Liverpool granite blocks were first laid in 1871, and wood in 1873.

Tar and gravel joints for stone pavements were adopted in London in 1869, and in Liverpool in 1872, though they had previously been in use in Manchester.

Glasgow first used granite block and wood for pavements in 1841, and asphalt in 1873.

Recent excavations show that the streets of Pompeii were paved with lava from Vesuvius. The pavement must have been laid some time previous to its destruction, as the blocks in many places show an appreciable wear, although the traffic must have been very slight when compared with modern times.

Sienkiewicz in his historical novel "The Deluge" says that the capital of Lithuania was paved with stone in 1655, and adds that this was something extraordinary for that time.

A history of Spanish times in the West Indies, after describing a visit of the pirates to Porto Bello, Venzuela, in 1668, says: "Having stripped the unfortunate city of almost everything but its tiles and paving-stones, the sea-rovers departed."

Although Paris had some pavements before London, it was many years before its streets were in even a decent condition.

Martin Lister, writing of Paris in 1698, says: "The pavements of the streets are all of square stones of about eight or ten inches thick; that is, as deep in the ground as they are broad on top, the gutters shallow and laid round without edges, which makes the coaches glide easily over them." On another page he says the material was a very hard sandstone, and that all the streets and avenues were paved.

Aaron Burr in 1811 thus describes their condition in a letter to a friend: "No sidewalks—the carts, cabriolets, and carriages of all sorts run up to the very houses. Most of the streets are paved as

Albany and New York were before the Revolution, some arched in the middle, and a little gutter on each side very near the houses. It is fine sport for the cabriolets or hack-drivers to run a wheel in one of these gutters, always full of filth, and bespatter fifty pedestrians who are braced against the wall."

A sample of asphalt macadam was laid on the road between Bordeaux and Rouen in 1840. This was a mixture of asphalt rock and ordinary stone, and was probably the first bituminous roadway laid on a public highway, although about the same time asphaltic rock was used for sidewalks on some of the streets of Paris.

In 1837 a Mr. Claridge obtained a patent for using Seyssel asphalt for paving purposes in the *Département de l'Ain.*

In 1854 the Rue Bergère was paved with compressed asphalt, followed by the Rue St. Honoré in 1858, from which time the success of asphalt pavements has been assured in Paris.

In the ruins of the ancient city of Palenque, Mexico, pavements of cut-stone blocks have been discovered which must have been laid at a very early period.

In the city of Mexico, from a very early date, cobblestones were used for pavements, and their use was continued till 1884, when a portion of the principal avenue of the city was paved with stone blocks. The stone being of a poor quality, the result was not satisfactory and the attempt was not repeated. Some five years later wooden blocks were tried, but the expansion was so great that the surface was deformed, and the experiment failed. Lumber being so expensive in Mexico, no further attempt was made with wood.

In 1889 some coal-tar pavement was laid, resulting in the usual failure, it being entirely torn up a year later and asphalt blocks substituted. Up to 1899 some 148,000 square yards of this material had been used upon a cobblestone and sand base with very satisfactory results. Since that time a large amount of sheet asphalt has been laid.

The first pavement in this country was laid in the little town of Pemaquid (Maine). A farmer at work in his field struck an obstruction with his plow, which, upon investigation, he found to be a curb stone, and upon excavating further a well paved street was disclosed. It has been thought that this pavement must have been laid in about 1625.

Pavements of cobblestone were laid in New York and Boston at about the same time.

Of the former city Mrs. John King Van Rensselaer in her popular novel "The Goode Vrowe of Manahatta" says that in the early days of New York the Dutch built several breweries on the road lying between Broad and Whitehall streets, since called Brower Street. The good housewives, annoyed by the dust raised by the heavy brewery wagons, made frequent complaints to the city authorities, who finally paved the roadway with small round stones. This created the greatest interest, and many visitors came to see the "stone road," which finally came to be and is now known as Stone Street. This was about 1656.

In Mrs. Lamb's "History of New York" it is stated that De Hoogh Street, now Stone Street, was paved in 1656; that the second was Bridge Street, in 1658; and that in 1660 all the streets most used were paved with cobblestones, the gutter being in the centre of the street, but no attempt was made to lay sidewalks.

A Swedish traveller, writing of New York in 1751, says: "The streets do not run so straight as those of Philadelphia and have sometimes considerable bendings; however they are very spacious and well built, and most of them are paved except in high places, where it has been found useless."

In New York cobblestones were almost the only paving material until 1849, although some experimental wooden blocks were laid on lower Broadway as early as 1835. On this same street "Russ" blocks were laid up as far as Franklin Street in 1849. These blocks came from Staten Island and were from 2 to 3 feet square. In 1855 the blocks on the grades were grooved to give better foothold to the horses. This pavement was replaced by the so-called Guidet blocks in 1868 or 1869.

A detailed report of the Council of Hygiene and Public Health made January 1, 1865, says that practically all of the New York pavements of that date were cobblestone or Belgian block. There was some Russ and a small piece of cast-iron block on Cortlandt Street.

Belgian blocks were first laid on the Bowery in 1852, and came into very general use after 1859. They made the improved pavement of the times.

The present-shaped granite blocks were first used in 1876 or 1877, though the Guidet patent plocks had been used a few years previously. This latter had also been adopted to some extent in Brooklyn, but never came into very general use. Its principal difference from the present pavement was in the size of the blocks, they being very large. Some of them measured on Atlantic Avenue, Brooklyn, in 1899 were 5 and 6 inches wide and 18 and 20 inches long.

The Dock Department used tar and gravel joints for a granite pavement on a sand foundation on Pier A, North River, in 1881, while the first concrete base for stone was regularly used in 1888 in the city streets. A small piece of asphalt was laid near the Battery in 1871.

A general scheme for the improvement of the pavements of New York was adopted in 1889. This was made possible by the legislation obtained the previous winter authorizing the issue of bonds for that work.

The first street paved in Boston was probably Washington Street, about 1650, the material being "pebbles." A portion of State Street was paved previous to 1684, and quite an amount of pavement was laid in the latter part of the seventeenth century. Many of the original paving petitions are now on file in the City Clerk's office, one bearing the date of 1714.

Drake's "History of Boston" says that on March 9, 1657, the General Court ordered "the paved lane by Mrs. Shrimpton's to be laid open and no more to be shut up." This is the year following the laying of the first pavement in New York, and would indicate that Boston began the work of paving as soon as, if not sooner than, New York.

Speaking of Boston in 1673: "Yet for several years after this there were no streets paved excepting a few sections of some of the principal ones, and those of a few rods in extent."

On April 19, 1704, £100 was voted for paving "such places of the streets as the selectmen should judge most needful, and therein to have particular regard to the Highway near old Mrs. Stoddard's house."

On March 29, 1706, £100 was voted "for paving the Mayn street towards the Landing to the south end of the Town, and £50 for paving at the lower end of the Town house."

In 1719 the General Court authorized the town to raise $2100 by a lottery towards paving and repairing the Neck, and soon afterwards authorized another to raise funds for paving the highway from Boston line to Meeting House Hill in Roxbury. Winter Street was paved about 1743.

Shutliff's "History of Boston" says: "In the year 1758 the townspeople began to pave the streets leading to the Neck partly at the expense of the town and partly by private subscription."

Baltimore paved its first street in 1781, using the ever-present cobblestones, which in 1899 composed about 75 per cent of its entire pavement.

Philadelphia. In 1726 a Friend relates that he saw paved streets near the court-house and Market House Square. Second Street from High to Chestnut Street was the first one regularly paved. In 1719 a gentleman writing to his brother in England says: "As to bricks, we have been upon regulating our pavements of our streets, the footway with bricks and the cartway with stones, which has made our bricks dear."

About the same time the minutes of the City Council state that, as several inhabitants have paved the streets with pebbles, an ordinance is recommended restraining the weights of loaded carriages passing over them. In 1761–2 an act was passed "Regulating, pitching, paving and cleansing the highways, streets, lanes, and alleys &c within the settled parts of Philadelphia." Curbstones were first adopted in 1786.

Philadelphia claims to have had macadam, or broken stone, streets or roads two hundred years ago, and was probably the pioneer in this country in that respect. Several streets were paved with hemlock blocks in 1839 and 1840, but with little success.

In 1884 Philadelphia had 535 miles of pavements, of which 93 per cent was cobble, 6¾ per cent granite, and 0.25 of one per cent asphalt. The granite, however, was not the present-shaped blocks, but practically like Belgian.

In that year a special commission of experts was appointed to report on the best material for street pavements, and the era of improved streets in that city began with the adoption and carrying out of the commissioners' report.

Chicago. In Chicago all street improvements previous to 1844

consisted in keeping the earth roadways in as good a condition as possible. From 1844 to 1855 the roadways of the most important streets were planked. In 1855 1.72 miles of actual pavement was laid, but of what material the reports do not state.

San Francisco. In the big fire that occurred in San Francisco in 1850, many planked streets were set on fire and consumed.

Roads constructed for short distances of natural asphalt in southern California had been known for a long time prior to 1870.

New Orleans. New Orleans constructed her first pavements of cobblestones in 1817, when the population of the city was about 41,000. Previous to this time it had not been deemed practicable to lay a pavement successfully on the soft yielding soil of the city. A general paving ordinance was passed in 1822, and under its provisions streets were improved with shells, cobble, square blocks, and irregular flat stones.

In 1837 an ordinance ordered certain streets paved with the "gunnels" of flat boats, although they had been used previous to that time.

In 1838 a portion of St. Charles Street was paved one-third with stone blocks, one-third with curbstones laid flat, and one-third with hexagonal pine blocks. The stone and wood blocks were satisfactory, and their use was continued.

A bituminous pavement of some kind was laid on Gravier Street in 1880, but proved a failure. Asphalt was first laid on St. Charles Street in 1885.

From 1889 to 1896 a number of streets were paved with gravel concrete, but the material did not give good satisfaction.

Brick was used in 1894, and chert in 1895.

The dimensions of granite blocks were $14 \times 10 \times 88$ inches.

Cleveland. The first stone pavements of Cleveland were constructed between 1851 and 1854, of Independence sandstone. The blocks had a surface of 8 or 10 by 12 inches and were from 8 to 12 inches deep.

Medina sandstone was first used in 1856, and the streets then paved were in good condition in 1880.

Nicholson pavement was laid in 1866. In 1873 an experiment was tried by laying a mixture of coal-tar and roofing-gravel to a

depth of three inches on six inches of broken stone. The results were not good.

St. Louis. Main Street in St. Louis was paved with stone in 1818. The blocks were roughly dressed, irregular in shape, from 3 to 12 inches thick, 6 to 14 inches long, and 6 to 10 inches deep, and set on 6 inches of sand. In 1842 the specifications called for a regular block 4 to 5 inches thick, 7 to 12 inches long, and 10 inches deep, set on 7 inches of gravel.

Macadam was adopted in 1832.

Wood has been experimented with in St. Louis to a great extent. In 1851 and 1852 many streets were planked. In 1867 Burnettized cottonwood was used. This pavement lasted about seven years, when it was replaced with untreated pine, which had about the same life.

Cobblestones were tried in 1855, but never came into general use.

Granite and asphalt blocks were adopted in 1873, and sheet asphalt in 1883.

Albany. In September, 1704, the City Council passed the following resolution: "It is also ordered that ye streets be paved before each inhabitant's door within this citty, eight foot breadth from their houses and lotts before ye 25th of October next ensueing, upon penalty of forfeiting the summe of 15s. for ye behoofe of ye Sheriffe, who is to sue for ye same."

In connection with the visit of Peter Kalm in 1749 it is stated that "the streets are broad and some of them are paved." In 1764 it appears from Mrs. Grant's "Memoirs of an American Lady" that State Street was only paved on each side, the middle being occupied with public edifices. Active paving work was not begun till about 1791, when Broadway was paved and complaint was made about the quantity of stones required, as "it swallowed up thousands of cartloads." Cobblestones were the only material used for years, dimension granite blocks having been not adopted until 1873.

CHAPTER II.

STONE.

The rocks that once formed the crust of the earth were composed almost entirely of nine elements, oxygen, silicon, magnesium, aluminum, calcium, iron, sodium, potassium, and carbon, the whole making 97.7 per cent of the earth's crust.

These elements combining in different ways formed minerals, and these minerals make the different rocks according to the number and quantity of their components.

Rock can be defined as any material forming a portion of the earth, whether hard or soft. Rocks are divided into two general classes, stratified and unstratified. Stratified rocks are more or less consolidated sediments and are of aqueous origin. Unstratified rocks, having been more or less completely fused, are crystalline in form and of igneous origin.

The igneous rocks, while not all granite in the strictest sense, may be called granitic, for they are granular and made up generally of the same substances as the granites, varying in their proportions and structure.

The minerals forming these rocks are generally considered as being divided into essential parts and characterizing and microscopic accessories. These terms are self-explanatory, the essential parts making up the body of the stone, the characterizing accessory defining its exact variety, and the microscopic being those contained in very minute quantities.

The important minerals that make up these rocks are quartz, feldspar, amphibole, pyroxene, and mica.

Quartz.

Quartz is a pure silica, composed of silicon and oxygen; its specific gravity is 2.65 and it is a hard and brittle mineral. It is

always found of the same composition and hardness, although the shape of its particles varies considerably. It is practically indestructible by the forces of nature, which accounts for its forming so large a proportion of all sands. Those found on the seashore are nearly all quartz. When absolutely pure, quartz is colorless, but sometimes it contains impurities enough to give it a color, when it is known as rose quartz, smoky quartz, etc., according to its appearance. When it is in a metamorphic state with its crystals cemented together with quartz, it forms a rock called quartzite.

Feldspar.

Feldspar is an anhydrous silicate of alumina together with soda, potash, or lime. It is generally softer than quartz, with a specific gravity of from 2.4 to 2.6. There are several varieties of feldspar; the principal ones being orthoclase, microcline, albite, oligoclase, and labradorite. It is also divided into two groups according to its crystallization, the monoclinic and the triclinic. The former contains principally silica, alumina, and potash; the latter with the exception of microcline, which chemically is almost the same as the monoclinics, has no potash, but in its stead sodium and lime. According as the above constituents vary in quality and quantity, the feldspars vary in hardness and color, and when they are in appreciable quantities they have an important bearing on the resulting rock. It is susceptible to the action of the elements, all clays being formed by the decomposition of feldspar.

Amphibole.

This mineral is sometimes called hornblende, which term really belongs to but one variety, of which there are two, the aluminous and the non-aluminous. The former contains about 45 per cent of silica, 17 of magnesia, 10 of alumina, 12 of lime, and 16 of iron oxides; the latter 57 per cent of silica, 26 of manganese, 14 of lime, with small amounts of oxide of iron and manganese. Hornblende belongs to the aluminous variety. Hornblende is hard and tough and imparts these characteristics to all rocks of which it becomes a part. It is found in some metamorphic rocks. Its color is generally a brownish green.

Pyroxene.

Pyroxene is more brittle than hornblende and consequently not so desirable a constituent for a rock. Its principal variety, augite, is an essential ingredient of diabase and basalt and also an accessory. It is dark-colored and composed approximately of silica 50 per cent, alumina 6 per cent, magnesia 15 per cent, lime 23 per cent, and iron oxides 6 per cent.

Mica.

This is the mineral so well and popularly known as isinglass. There are several varieties, but the two found in granite rocks are muscovite and biotite. They are always found in thin sheetlike forms and are important factors in the make-up of rock, both as to color and structure. They are influential disintegrating agents, as, on account of their laminations, they often allow the entrance of moisture, which is an important element of decay in any material. If the mica is deposited in different layers or planes, the rock readily splits along these planes. If muscovite is the variety present, the rock is generally light-colored, while the black biotite imparts its color to the stone, often giving it a speckled appearance. Muscovite is a silicate of potash and alumina, and biotite of alumina, iron, and magnesia.

Having somewhat hastily examined these mineral constituents of the granite rocks, it will now be in order to take up the rocks themselves. They are complex in their composition and structure, having been formed at different times and under different conditions; some containing but few and others many minerals, often grading into each other so imperceptibly that it is sometimes almost impossible to determine where one variety ends and the other begins. For this reason, and on account of the different definitions given to the same variety by equally good authorities, it seems proper to treat these rocks as one class, each according to its characteristics, and not attempt to make any arbitrary class distinctions.

The group of rocks which it is proposed to study in this connection may be defined as silicious, holocrystalline, granular rocks. Their essential constituents are quartz and feldspar, and the characterizing accessories hornblende, pyroxene, and mica, with some

other less important minerals. Microscopic accessories occur, but in such small quantities that they will not be taken up. In some varieties hornblende and pyroxene are considered essential.

Granite, according to Dana, consists of quartz, feldspar, and mica. Under this definition, no stone could be a granite unless it contained mica, but as the term is used commercially it includes syenite and gneiss and often porphyry. The order of the consolidation of rocks is an important factor in their structure. As a rule, in granite the minor accessory minerals crystallized first, taking their natural form. According to some authorities the ferro-magnesian minerals came next, followed by the feldspars, and lastly by the quartz flowing in, filling all the interstices, making a complete and solid rock. Occasionally, however, quartz and feldspar are found completely intermingled, indicating that they crystallized at the same time.

While the character of a granite is determined principally by its essentials, the accessories have much to do with its quality. The color is generally fixed by the feldspar, but the mica is often a governing characteristic, the presence of muscovite making a granite light, while biotite has always the opposite effect. A large amount of quartz will make a granite hard and brittle, while too much feldspar renders it softer and tougher, but more liable to decomposition. The susceptibility to polish and its ability to resist the action of the elements depend greatly upon the accessory components. Hornblende is a mineral which permits a granite to take a high polish, while pyroxene, being very brittle, often breaks out when a stone is being hammer-dressed, giving a pitted appearance to an otherwise smooth surface. Iron is detrimental, as by the action of the weather iron-rust is formed, and rains washing it over the surface of the stone produce stains upon any structure built of stone containing iron. The size of the particles of the minerals is important. The smaller the grains and the more evenly they are distributed, the better the stone will cut and be polished. The finer the grain the better satisfaction the granite will give in cut work. A fine-grained stone is compact in texture, excluding air and moisture, two agents that are constantly at work to destroy all minerals. Granite is divided into varieties according to the presence of its varying accessories.

Muscovite granite is so called from the mica being of the muscovite variety. It is not found in large quantities in this country, but is produced to some extent from the quarries of Barre, Vt.

Biotite granite is similar to the above except that the muscovite is replaced by biotite. On this account, while the former is always light in color, the latter varies from light to dark according to the quantity of mica or the color of the feldspar. This class of stone is often red, owing to the red feldspar. As a rule the stone is hard and tough. Good samples of it are found at Westerly, R. I., and Dix Island, Me.

Muscovite biotite granite stands between the two last described, having both varieties of the mica, and differing from them only in that respect. It is found at Concord and several other places in New Hampshire.

Hornblende granite is a variety in which the characterizing accessory is almost entirely hornblende. Biotite is, however, generally found upon a microscopic examination. When the mica cannot be discovered by the unaided eye the name "hornblende" is given to the variety. Examples of this are found at Peabody, Mass., and Mt. Desert, Me.

Hornblende-biotite granite is distinguished from the above in that it contains as essentials quartz and feldspar with both hornblende and biotite. This combination gives a dark and sometimes an almost black granite, capable of receiving a fine polish.

Examples of this stone are found at St. George, Me., Cape Ann, Mass., and at Sauk Rapids, Minn.

One important property that is possessed by all granites is that of splitting more easily in one direction than another, so that it is easy to get out blocks large or small with practically parallel sides. This property is generally called rift or cleavage. It was caused by pressure before the rock was consolidated. The rift is always perpendicular to the line of pressure. When a stone is resting upon a face parallel to its cleavage plane it is said to be lying on its bed, and the face at right angles to the bed is called the edge. Rift is governed by the amount of pressure and the grain of the stone, so that while all granites have a rift they do not have it in the same degree. The finer-grained granites have the best rift, decreasing as the grains increase, so that a coarse-grained

variety is apt to be bunchy and requires considerable dressing to bring the faces of the block to a plane surface. This fact is well known to quarrymen, and an experienced hand will easily and quickly tell the character of the rift by the general appearance of the stone.

Although it has been said that granite breaks more easily in one direction than another, on account of its peculiar structure it can be broken into blocks of almost any shape by skilled workmen with a stone-hammer, or with proper wedges if a large and irregular block be required. By this method the dividing force is exerted in whatever direction desired by inserting the wedges into holes drilled for the purpose, when by lightly driving the wedges in succession the quartz which is holding the other crystals together is easily fractured and the granite breaks as desired. On account of this fact it is particularly adapted for paving-blocks and curbing, as it is cheaply and rapidly formed into the proper size and shape. Often a stone is barred from use as a paving material for the reason that so much work is required to get it down to specification size.

Gneiss is a variety of granite which differs from that just described only from the fact that its rift is caused by the greater portion of its mica being gathered in parallel planes so that the stone is easily broken along these planes. This is purely a physical difference, as chemically and mineralogically it is the same as granite proper. This arrangement of the mica weakens the stone appreciably when set on edge, a fact which is not true of the granites.

Dana defines gneiss as consisting of quartz, feldspar, and mica, and possessing cleavage planes.

Syenite, according to Dana, consists of feldspar and hornblende with or without quartz. It will be noticed that the mica of granite and gneiss has disappeared and hornblende has taken its place. This latter mineral is hard and compact, varying considerably in its composition, but made up principally of silicate of magnesium and calcium, with some alumina and iron. It has its cleavage in two planes and is easily brought to a fine polish.

In 1787 Werner adopted the definition quoted above from Dana, but later German geologists have used the term syenite to designate rocks without quartz, differing only from granite in that

respect and consisting mainly of orthoclase feldspar in company with one or more minerals of the amphibole (hornblende) or pyroxene group. This combination has seldom been used or found in this country.

Porphyry.—The mineral and chemical composition of the quartz porphyries is essentially the same as that of the granites, from which they differ mainly in their "porphyritic" structure. That is, the quartz has cooled first, thereby gaining a crystalline form so that the rock presents to the eye a dense compact mass of stone in which can be seen crystals of quartz alone or quartz and feldspar together. This structure characterizes all the rocks of this type. The ferromagnesian minerals are often confined to the elements of the earlier period of crystallization, while the original quartz is found in the acid types only, and is generally restricted to the ground-mass.

This change of structure prevents the formation of the rift so characteristic of the true granites. In composition it is generally about two-thirds silica.

Diabase (Trap-rock).—The essential constituents are plagioclase, feldspar, and augite, with nearly always magnetite and apatite in small proportions. The accessories are hornblende, biotite, olivine, etc. It is holocrystalline in form, but not often having perfect crystal outlines, as they are more or less distorted on account of interference during the process of formation. The feldspar generally crystallizes before the ferromagnesian constituent, the former being often found wrapped around by the augite. As a rule it is finer-grained than the granites. It varies in color according to its constituents from a dark gray to almost black. The rock is hard, compact, and tough, but not easily broken into regular shapes. It occurs in dikes, where the material in a melted state poured into the fissures already created and, cooling, there divided masses of the same character into separate and distinct parts. This is often seen in limestone formations in Maine. The best illustration of trap-rock in this country is probably the Palisades of New Jersey, although it is also found in Connecticut, Pennsylvania, and Virginia. It has a specific gravity of from 2.8 to 3.2.

Basalt.—This rock does not differ materially from diabase, but

is of more recent origin. The essential minerals are augite and plagioclase feldspar with olivine. The accessories are different varieties of iron and apatite with sometimes quartz, mica, etc. Structurally it varies from the glassy to the holocrystalline. Chemically it is composed of silica 50 per cent, alumina 14, lime 10, magnesia 6, oxide of iron and manganese 12, and soda 4 per cent, with small quantities of potash, etc. In the United States it is found principally west of the Mississippi, and especially in California and Oregon. It is generally finer-grained than trap-rock. It was used very generally by the early road-builders of the old country, being carried great distances to form the surface of the roads on account of its fine wearing qualities.

Sioux Falls Stone.

This is a red quartzite or metamorphic sandstone. It contains 85 per cent of quartz. Its color is due to oxide of iron. It is said to be the hardest stone in the country. It weighs 162 lbs. per cubic foot and has a crushing strength of 28,000 lbs. per inch. On account of its hardness it is not much used for building purposes, but has been to some extent in Western cities for pavements. It wears smooth with a glassy surface.

ANALYSIS OF GRANITE FROM PORT DEPOSIT, MD.

	Per cent.
Silica	73.690
Alumina	12.891
Ferric iron	1.023
Ferrous oxide	2.585
Lime	3.737
Magnesia	.498
Potash	1.481
Soda	2.811
Water	1.060
Total	99.776

The mineral composition of this rock was calculated from the above analysis, but nothing more than an approximate result could be expected because the exact composition of the minerals is not known. It was supposed to be:

	Per cent.
Biotite	9.7
Feldspars	46.4
Quartz	40.0
Epidote	3.9
	100.0

Its crushing strength was 21,180 lbs. per square inch.

GRANITE FROM WATERFORD, CONN.

	Per cent.
Silica	68.11
Alumina	14.28
Ferrous oxide	2.63
Lime	1.86
Magnesia	.68
Sulphur	.34
Oxide of potassium	5.46
Oxide of sodium	6.57
Total	99.93

An average of the tests made of this stone showed a crushing strength of 23,715 lbs. per square inch.

GRANITE FROM BLUE HILL, ME.

	Per cent.
Water	0.27
Silica	74.64
Ferric oxide	1.56
Alumina	14.90
Lime	.39
Magnesia	Trace
Potassium oxide	6.88
Sodium oxide	.41
	99.05

From this analysis the mineral composition was calculated to be:

	Per cent.
Mica	35
Feldspar	10
Quartz	55
	100

GRANITE FROM NORTH JAY, ME.

	Per cent.
Silica	71.54
Titanic oxide and iron peroxide	0.84
Alumina	14.24
Ferric oxide	.74
Ferrous oxide	1.18
Lime	.98
Magnesia	.34
Soda	3.39
Potash	4.73
Water	.61
Sulphur and carbon dioxide	Trace
	98.59

This rock is described as an even-grained white granite composed of white feldspar, quartz, biotite, and muscovite, with a small grain of red garnet. Its name is biotite muscovite granite. It showed a crushing strength of 16,310 lbs. per square inch.

A red granite from the same place had a strength of 22,367 lbs. per square inch.

PINK GRANITE FROM MILFORD, MASS.

	Per cent.
Silica	76.07
Alumina	12.67
Ferric oxide	2.00
Oxide of manganese	.03
Lime	.85
Magnesia	.10
Potash	4.71
Soda	3.37
	99.80

Its compressive strength was 20,883 lbs. per square inch.

DARK GRANITE FROM BARRE, VT.

	Per cent.
Silica	69.56
Ferric oxide	2.65
Alumina	15.38
Manganese	Trace

	Per cent.
Lime	1.76
Magnesia	Trace
Sodium oxide	5.38
Potassium oxide	4.31
Loss on ignition	1.02
	100.06

This specimen is described as a fine, even-grained typical granite containing both biotite and muscovite with quartz and feldspar. Its specific gravity is 2.672. It had a crushing strength of 17,254 lbs. per square inch, weight applied perpendicular to the rift, and 19,957 lbs. parallel to rift.

GRANITE FROM PETERSBURG, VA.

	Per cent.
Silica	64.12
Alumina	20.91
Oxide of iron	2.96
Lime	1.98
Magnesia	.66
Sodium oxide	4.57
Potassium oxide	4.82
	100.02

Its composition was:

	Per cent.
Mica	15
Feldspar	60
Quartz	25
	100

Its crushing strength was 25,100 lbs. per square inch.

GRANITE FROM QUINCY, MASS.

	Per cent.
Silica	75.14
Alumina	15.57
Ferrous oxide	2.49
Lime	1.85
Potash	.54
Soda	4.41
	100.00

Its mineral constituents are principally quartz, hornblende, and feldspar. The stone is very hard and capable of receiving a high

polish. Its crushing strength was found by Gillmore to be 17,750 lbs. per square inch, and its specific gravity 2.669.

GRANITE FROM EXETER, CAL.

	Per cent.
Silica	75.35
Oxide of iron	3.94
Oxide of aluminum	13.69
Oxide of calcium	2.97
Oxide of magnesium	.06
Oxide of sodium	1.14
Oxide of potassium	2.85
	100.00

This stone has a shearing strength of 2419 lbs. per square inch and a coefficient of expansion of 0.00000461 per inch. Granite from Millbridge had a coefficient of expansion of 0.000004 between 32° and 212° F.

The total granite output of the United States for 1909 and 1910 was valued at $19,581,597 and $20,541,967, respectively, as against $7,944,994 and $8,905,075 in 1896 and 1897, Vermont, Massachusetts, Maine, Wisconsin, and New Hampshire producing the most, and in the order named.

The number and value of the granite paving-blocks made in 1909 and 1910 were:

1909		1910	
Number.	Value.	Number.	Value.
57,873,150	$2,743,117	57,089,399	$2,823,772

Of these blocks nearly all come from five states, as follows:

	1909		1910	
	Number.	Value.	Number.	Value.
Wisconsin	18,798,977	$982,798	15,996,780	$939,020
Maine	6,137,682	262,825	10,893,020	548,374
Massachusetts	6,878,872	308,203	4,532,685	201,425
North Carolina	5,062,500	214,508	3,499,497	164,265
Georgia	3,384,600	93,300	4,966,493	195,207

In 1897 Georgia supplied $295,000 worth, Massachusetts $243,750, and Maine only $172,637. This small amount was undoubtedly caused by the fact that between 1890 and 1900

in the City of New York and neighboring cities there was a great demand for smooth and quiet pavement, which resulted in a large amount of asphalt being used and a comparatively small amount of stone. The pendulum swung back, however, in the next decade, and now asphalt is being replaced with stone in material quantities.

ANALYSIS OF TRAP-ROCK FROM MERIDEN, CONN.

	Per cent.
Silica	52.37
Aluminum oxide	15.06
Ferric oxide	2.34
Ferrous oxide	9.82
Titanium oxide	.21
Manganous oxide	.32
Magnesium oxide	5.38
Calcium oxide	7.33
Potassium oxide	.92
Sodium oxide	4.04
Water	2.24
	100.03

This stone had a crushing strength of 34,920 lbs. per square inch and a specific gravity of 2.965.

TRAP-ROCK FROM MONSON, MASS.	Per cent.
Silica	52.59
Ferric oxide	14.55
Alumina	23.42
Lime	9.05
Magnesia	.28
Manganous oxide	.09
	99.98

Specific gravity 3.01.

BIRDSBOROUGH TRAP-ROCK, PENN.	Per cent.
Silica	46.87
Alumina	13.36
Ferrous oxide	2.71
Ferric oxide	9.79
Calcium oxide	14.70
Magnesium oxide	4.35
Sodium oxide	4.64
Potassium oxide	2.01
Titanium oxide	1.98
	100.41

From the above and microscopic examinations the mineral constituents were found to be plagioclase, feldspar, pyroxene, and hornblende, with 4.56 per cent of magnetite or magnetic iron. This is a stone similar to that forming the Palisades of the Hudson in New Jersey.

TABLE No. 1.

ANALYSIS OF TRAP-ROCK FROM NEW JERSEY.

	Per cent.	Per cent.	Per cent.	Per cent.
Silica	50.61	52.29	50.03	51.20
Iron	13.91	14.30	16.81	11.12
Alumina	18.34	16.68	18.20	20.88
Lime	7.01	9.35	11.10	12.50
Magnesia	6.73	4.58	1.02	2.17
Potash	0.08	0.48)	1.03	1.03
Soda	1.60	2.80)	....	....
Water	1.72	....	1.80	1.10
	100.00	100.48	100.00	100.00

* New Jersey Report, 1898.

TABLE No. 2.

RESULTS OF TESTS MADE OF CRUSHING STRENGTHS OF DIFFERENT GRANITES.

Locality.	Position. Bed.	Position. Edge	Authority.
Middleton, Conn.	23013	23049	I. H. Woolson, Col. College
Do.	22548	21699	Do.
Do.	31881	30996	Do.
Barre, Vt.	17254	19957	Wm. C. Day, Swarthmore Col.
Do.	16412	15845	Do.
Lithoria, Ga.	26880		Watertown Arsenal
Stone Mt., Ga.	28953		Do.
North Jay, Me., white	16310		Do.
Do. red	22367		Do.
Westfield, Mass.	16091		Do.
Exeter, Cal.	21104		Do.
Milford, Mass.	20883		Do.
Port Deposit, Md.	21180		Booth, Garrett & Blair, Phil.
Brandywine Granite Co.*	25075		Do.
Mount Airy, N. C.	20000		Riehlé Bros., Phila.
Waterford, Conn.	23715		I. H. Woolson, Col. College
Graniteville, Mo.	24749		J. B. Johnson, Wash. Univ.

* Gneiss.

Sandstone.

Sand is formed by the decomposition or disintegration of rocks. It is a common occurrence to find pockets of sand in beds of earth or limestone. These are the result of boulders being surrounded

when these deposits of clay or stone were first made. Long afterwards the boulders decayed, and in their places are discovered pockets of sand. Its composition depends upon the minerals contained in the original rocks.

When large deposits of stone decay, the particles of quartz, being indestructible, are borne away principally by two agencies, water and the winds. At this time the different products are often separated and the quartz, being heavier than the decomposed mineral, is kept by itself, as in the case of the sands of the seashore and those of a desert.

Large grains are as a rule affected more than small ones. Sea sands are less sharp than those of rivers and lakes, on account of the constant action of the waves and tides; while those of a desert or any place subject to the action of the winds are most rounded of all. It is only in desert sands that the smallest grains show any great effect of attrition.

Sandstone is formed by grains of sand being deposited in beds by some agency and afterwards compacted. The sand proper is almost all quartz, as this mineral is indestructible from the ordinary action of the elements, while the cementing portion of the original rock has generally been decomposed and a new substance formed. The solidification of the stone is caused by great pressure, partial solution, fusion of some of its own parts, or by the infiltration of some cementing material, such as silica lime, or the oxides of iron. It is generally found in layers of variable thickness separated from each other by some softer material. The thickness of these layers probably depends upon the time one force acted continuously upon the sand, the softer deposits being made during the intervening period.

The texture of the stone varies according to the sizes of the sand-grains, some being so fine as to be barely discernible, while others are very coarse, with every gradation between them. Mica and feldspar are sometimes ingredients, and upon the composition, as well as the cementing material with which it is held together, depends its value as stone.

Sandstones are of many colors, the most common, however, being gray, yellow, and red. These colors are determined by the different combinations of iron; the red being due to peroxides, and

the yellow to hydrous peroxides. Some varieties will change color upon exposure to the air or the application of heat, on account of the oxidation of the iron.

When the rock is solidified by any of the methods mentioned above, except pressure, the cementing substance must be considered as having been formed in place, and upon its complete formation the rock may be said to have entered upon a new era in its history.

When the cement is calcareous, it has generally been deposited as mud or pulverized shells, but it has no binding properties until it has been partially dissolved and redeposited in a somewhat crystalline form. This cement is sometimes mixed with red oxide and brown hydrated oxide of iron.

In the hard and tougher sandstones the cement is generally silicious. If the grains have not been much rounded and are of irregular size, the interstices are very small and the silica is of no great amount and often hard to discover, as it may be hidden by dust or iron-stains. When the spaces are comparatively large the silicious cement is often deposited around the quartz-grains, increasing their size and completing the rock by a regular growth. Red sandstones are sometimes found to be easily disintegrated on account of the iron oxide separating the original grains from the cementing material.

In street construction sandstones are used for curbing, cross-walks, flagging, and for paving the roadway of the street. Those most commonly used for these purposes in this country are the so-called Hudson River bluestone, Medina sandstone, Berea grit, and Colorado sandstone. The Medina stone and that from Colorado and Minnesota are the only ones of these used in pavements proper.

Kettle River Sandstone.

The quarries from which this stone is taken are situated in a deep gorge of the Kettle River, at Sandstone, Minn., halfway between Minneapolis and Duluth.

It is a pinkish-brown in color and sufficiently soft to carve readily. Under the microscope it seems to consist almost of rounded and irregular quartz grains lying in close contact with apparently little interstitial material.

It is used largely in building construction, but also in street pavements, as well as for curbing. It has a compressive strength of between 12,000 and 13,000 pounds per square inch. Its chemical composition is:

Silica	97.10
Alumina	2.20
Lime	0.60
Magnesia	0.10
	100.00

Although softer than granite it is hard enough for paving-blocks and has been used extensively in cities in Minnesota, Missouri, Wisconsin, and in small amounts in Nebraska, North Dakota, Iowa, and in certain parts of Canada. On account of its comparative softness it wears smooth and even, while its gritty make-up prevents it from being slippery.

Hudson River Bluestone.

This variety is not generally considered to be a sandstone, but is known commercially in the localities where it is used as "bluestone." It is very hard and durable and is used almost entirely for curbing, flagging, and cross-walks, for which purpose it is so well adapted on account of its great transverse strength. It is also very evenly bedded, so that its surface is smooth, making it especially desirable for sidewalks.

This formation extends about 100 miles in New York from the southwestern towns of Albany County across Greene, Ulster, Orange, and Sullivan counties to the Delaware River. The land along this line is of little worth for any agricultural purposes, its value being governed by the amount and quality of the stone it can produce. The different quarries vary much in the number and thickness of the quarry-beds, as well as the amount of the overlying earth. The beds range in thickness from an inch up to three feet, and in a few cases to six feet, the thinner layers being near the surface.

The strata can generally be split in places parallel to the bedding and to the required thickness, the size of the pieces being determined by the vertical joints. Stones sixty by twenty feet have in some instances being obtained.

The product of the different quarries varies somewhat in color as well as hardness and texture, and consequently in value. The texture ranges from the fine shaly or argillaceous to the silicious and even the conglomerate rock. The best is fine-grained, not very plainly laminated, and is composed almost entirely of silica cemented together by a silicious paste. It is therefore very hard and durable. It is so compact that it absorbs but little moisture and dries off quickly after a rain. A representative specimen had a specific gravity of 2.751 and contained 4.63 per cent of ferrous and 0.79 per cent of ferric oxide. It absorbed 0.82 per cent of water. At a temperature of from 1200° to 1400° F. its color changed to a dull red, and the piece was slightly checked and its strength impaired.

Stone very similar to the Hudson River variety is found in Luzerne County, Penn. A sample of this being analyzed showed:

	Per cent.
Silica and insoluble matter	94.00
Ferric oxide	1.98
Lime	1.10
Magnesia	1.00
Water and carbonic acid (volatile at red heat)	1.92
Alumina	Trace
	100.00

Its specific gravity was 2.656.

Medina Sandstone.

This stone is found in New York State, extending from Oneida and Oswego counties on the east along the shores of Lake Ontario westerly to the Niagara River. It also continues on into Canada, and is found to some extent in Pennsylvania and Virginia. It is of the Upper Silurian formation. It is generally a deep brownish red in color, though sometimes light and yellowish, and in a few localities gray. The coloring-matter is oxide of iron. In some instances where the red stone joins the gray, the iron has penetrated the latter to quite an extent. It is both fine- and coarse-grained in texture, the latter being of a deeper color as the iron cement more easily penetrates the interstices between the larger grains. The gray stone often contains marine shells, but these are rarely found in the red. The metals in composition are copper

and iron pyrites, oxide of manganese and iron, and carbonates of copper. Alternate freezing and thawing produce but little change in its strength. At Fulton, Oswego County, it forms the banks and falls of the river, and is noticeable for a half mile below, being formed in layers about two feet thick. At one quarry near Lockport layers are found varying in thickness from an eighth to a quarter of an inch up to several feet, and in another from a few inches up to six feet. These layers are easily separated from each other, as they are partially covered with oxide of manganese.

On the Niagara River the stone is nearly white, but on going east it becomes tinged with red, and at Medina the layers are very strongly colored, and sometimes spotted red and white.

The principal mineral constituent is quartz associated with some kaolinized feldspar. The cementing material is mainly oxide of iron with some carbonate of lime. It is evenly bedded, and the strata dip to the south. The beds are divided into blocks by systems of vertical joints, generally at right angles to each other. greatly facilitating the work of quarrying.

While quarries have been opened in many counties, the principal ones are located between Brockport and Lockport in Monroe and Niagara counties. At Medina the stone is hard, with oblique laminations in the bed. The gray stone is nearly all used for paving-blocks, although other colors are so used as well as for flagging and cross-walks.

A sample from Albion, Orleans County, had a specific gravity of 2.60. It had 0.51 per cent of ferrous and 0.06 per cent of ferric iron and absorbed 2.37 per cent of water. One from Oswego Falls had a specific gravity of 2.62 per cent, contained 0.59 per cent of ferrous and 1.71 per cent of ferric iron, and absorbed 3.73 per cent of water.

Potsdam Sandstone.

This formation is the oldest of any in New York in which sandstone is quarried. It is found in several counties in the State. It is grayish, yellow, brown, and sometimes red in color, according to the amount and kind of iron in composition. It varies from a strong compact quartzite to a loosely coherent granular mass.

The largest quarries are near Potsdam, hence its name. This stone is hard and compact, evenly grained, and reddish in color. It is largely used as a building-stone and also for pavements.

It was used to some extent in the Columbia College buildings.

It consists almost entirely of quartz, the grains being very clear, many of them showing a secondary enlargement. The cementing material is almost wholly silica. It absorbed 2.08 per cent of water, and has a specific gravity of 2.6. Under the heat test its color was unchanged. No checks appeared, and its strength was but little impaired.

Berea Sandstone.

This stone has an area in Ohio alone of about 15,000 square miles, and it also extends into four adjacent States. It is a well-defined deposit, moderately coarse-grained, from forty to sixty feet thick. It is generally gray in color, but sometimes spotted with iron stains, and in some localities a light buff or drab. It is quarried in great quantities at Berea, Ohio, whence it derives its name of "Berea grit." At that place it is covered by the Cuyahoga shale and by drift clay. At Peninsula, however, the formation is from thirty to sixty feet above the canal, making the quarrying work very easy. It is of great value for building-stone, as it is easily gotten out into regular shapes and is cut without difficulty. It is the best grindstone grit in the country. It is sufficiently porous below the surface to carry petroleum, gas, etc. It is too soft for paving purposes, but is used very generally for curbing and flagging.

The formation is supposed to represent an old shore-line, as much of the surface is ripple-marked and shows many signs of worms. An analysis of an average sample gave:

Silica	96.90
Iron oxide	1.68
Lime	.55
Potash and soda	.55
Carbonic acid, water, etc.	.32
	100.00

CRUSHING STRENGTH.	
Bed	17,500
Edge	14,812

Heated to 1200° to 1400° F. its color changed to red and its strength was entirely gone.

Gillmore found the crushing strength of sandstones to vary from 4025 to 17,725 lbs. per square inch.

Colorado Sandstone.

In Boulder County, Colorado, are several deposits of sandstone that furnish stone for building and street-construction purposes. The products have been used principally in Denver and Omaha, but are scattered about in many smaller towns in both States.

The stone varies in color from a gray to a light red according to the composition of the iron compounds.

It is generally found in layers from $\frac{1}{8}$ inch to several feet in thickness at an angle of about 30° with the horizon. It splits easily along the cleavage planes, and breaks readily at right angles, so that it is formed into flagging, curbstones, and paving-blocks without difficulty. It is hard and tough and wears well and smoothly in a pavement. Its grain and texture are such that, although smooth, it is never slippery, and, when laid on an unyielding base, after a little wear it forms a smooth and pleasing pavement, very similar to one made of Medina stone.

The following table shows the results of tests of Colorado sandstone, made for the State Capitol and given in "U. S. Mineral Resources" for 1886:

TABLE No. 3.

Locality.	Color.	Position.	Crushing Strength per sq. in.	Specific Gravity.
St. Vrains	Light red	Bed	11505	2.393
		Edge	17187	....
Fort Collins..........	Gray	Bed	11707	2.252
		Edge	10784	....
Do.	Light red	Bed	12740	2.432
		Edge	17487	....
Stout..............	Dark gray	Bed	10514	2.263
		Edge	12585	....
Buck Horn..........	Grayish white	Bed	18573	2.379
		Edge	17261	....

ANALYSIS OF COLORADO SANDSTONE.

	Stout. Per cent.	Buck Horn. Per cent.
Silica	95.50	96.45
Iron and alumina	0.78	1.90
Calcium oxide	0.88	1.06
Magnesia	1.45	0.64
Carbonic acid and water	1.18	0.00
	99.79	100.05

Limestone.

Although limestone as well as sandstone is a sedimentary rock, it differs from it very much in its formation.

Water flowing down from a rough mountainous country carries with it a large amount of matter both in solution and suspension. As the stream reaches any large body of still water its velocity gradually decreases and that portion in suspension is deposited, the coarser and heavier near the shore and the finer farther out.

Calcareous matter as a rule, being soft, is generally fine and is borne from a distance and finally deposited as silt. All waters flowing as above contain a considerable quantity of lime in solution which, being in part precipitated, serves to consolidate the silt. From this same source certain marine animals derive their supply for their shells. Upon the death and decomposition of the animal life the shells and corals are left and, breaking up, in time form calcareous banks which later on become beds of limestones of more or less fragmental nature.

The theory of the formation of oolitic varieties is somewhat different. It is supposed that certain fragments of calcareous matter have been deposited upon the bottom of some ancient sea, and that they were kept in motion by the action of the waves or some other force, preventing their solidification. If, then, the lime in solution should from any cause become too much for the absorption of the marine animals, it would be precipitated, and would form around the fragments, which, being in motion, would become approximately spherical in shape. But as the precipitation continues the interstices become filled and beds of solid stone are formed having the appearance peculiar to this variety.

Both of the above formations are generally in well-defined beds

nearly level when not disturbed by any subsequent force. When, however, as often happens, the strata are found at all angles with the horizontal, they have been acted upon by some of the forces so frequent during the formation of the earth's crust.

In the course of time some of these beds may be broken up into fragments comparatively small and after having settled into a permanent position and again consolidated by the further deposits of lime or iron oxides in the interstices of the fragments. It is thus that the metamorphic limestones are formed.

Limestones differ greatly in structure from the variety highly charged with fossils to the hard compact rocks denser and heavier than granite.

They also vary in color according to the iron and carbonaceous compounds that may be present.

As calcite crystallizes so readily, few limestones are entirely amorphous, but range gradually from the amorphic to the holocrystalline. Few limestones are pure calcium carbonate. Impurities are easily mixed with the lime during the formation. Magnesium is often found in considerable quantities, when the variety is called magnesian. When this amount exceeds 45.65 per cent the stone takes the name of dolomite. Dolomite has a specific gravity of about 2.9.

Silica and clay are often found in composition, and when they exist in quantities exceeding 10 per cent the stone is said to be hydraulic. That is, upon being burned and ground it can be made into mortar that will harden under water, a property not belonging to ordinary limestones. A specimen of this variety from Rondout, N. Y., analyzed according to Dana:

	Per cent.
Carbonic acid	34.20
Lime	25.50
Magnesia	12.35
Silica	15.37
Alumina	9.13
Sesquioxide of iron	2.25
	98.80

Marble is a name given to certain crystalline limestones that are of such a character as to be capable of receiving a high polish and so become of value for building purposes. Certain dolomites are also called marble.

Bedford Oolitic Limestone.

This stone is properly a calcareous sandstone or freestone, differing from sandstone in having its grains composed of carbonate of lime instead of quartz, and in the grains being small fossils instead of sediment transported by water from some former rock-mass. It differs from other limestone in its granular texture and freestone grain.

It occurs in a bed varying from 25 to 100 feet in thickness. The greater portion of it is free from laminations or bedding seams. In almost every quarry or natural exposure there is at least one system of vertical joints, but they are rarely so numerous as to prevent the occurrence of the stone in large dimensions.

It is a granular stone, and both the grains and uniting cement are carbonate of lime. In the common sandstones the grains are hard and approximately angular; in this stone the grains are always soft and either round or rounded. In the silicious sandstones the grains are harder than the cement, in the Bedford the cement is harder than the grains. These grains are nearly all small fossil forms, but when they are large, that portion of the stone containing them is thrown away and not used, the finest-grained being much the better if it is uniform in texture and color. The original color was blue, but it is sometimes found buff and even a mixed blue and buff, according to the chemical changes in the iron compound.

It is found in several counties of Indiana and extends across the Ohio River into the State of Kentucky. It takes its name from the village of Bedford, Indiana.

A series of tests to determine its compressive strength gave an average of 7000 lbs. per square inch with a maximum of 13,200 lbs.

Experiments on 1-inch cubes were also made to ascertain its fire-resisting qualities. Heated to 1000° F. and plunged into cold water the samples were not affected. Heated to 1200° and treated in the same manner the cubes crumbled slightly along the lower edges. Heated to 1500° and cooled in the air the cubes retained their form, but were calcined in a marked degree.

The principal use of this stone is for building purposes. It is easily cut when taken from the quarry, but hardens upon exposure to the atmosphere. It is also used in street construction for curbing and flagging, being easily sawed to any required dimensions.

TABLE NO. 4.

ANALYSIS OF BEDFORD STONE FROM DIFFERENT LOCALITIES.

Quarry.	Crushing Strength.	Specific Gravity.	Calcium Carbonate.	Magnesium Carbonate.	Insoluble Residue.	Iron Oxide and Alumina.	Total.
Bedford, Ind.	5600	2.47	98.27	0.84	0.64	0.15	99.90
Hunter Valley	4100	......	98.11	0.92	0.86	0.16	100.05
Romona	9100	2.48	97.90	0.65	1.26	0.18	99.99
Twin Creek	9900	2.51	98.16	0.97	0.76	0.15	100.04

Trenton Limestone.

This deposit takes its name from a township in Oneida County, New York. It is one of the most important in this country, extending from Maine on the east to the Rocky Mountains on the west and from Hudson's Bay to Alabama. By its decay it has formed soils of great fertility. That of the celebrated Blue Grass region of Kentucky is a direct product of the decomposition of this stone.

In its original locality it is dark blue in color, verging to black and lying in even beds which are sometimes separated by layers of black shale. It contains well-preserved specimens of the Lower Silurian Age. It changes in color and composition as it extends in different directions, but is easily followed by its distinctive features.

It is used for building purposes, burned into lime, and broken up for road-building, according to the wants of any particular section where it is located.

Table No. 5 gives the result of several analyses of this stone.

TABLE NO. 5.

	Specific Gravity.	Carbonate of Lime.	Carbonate of Magnesia.	Aluminum and Iron and Manganese Oxides.	Phosphoric Acid	Sulphuric Acid.	Potash.	Soda.	Silica and Silicates.
Average of 7 specimens non-magnesian	2.698	90.976	1.828	2.155	.489	.453	.470	.265	3.794
Average of 11 specimens magnesian	2.681	64.323	23.541	3.410	.414	.632	.590	.278	6.078

Table No. 6 shows the analyses of different limestones and their resulting limes.

TABLE No. 6

	Bridgeport, Penn.		Longview, Ala.		Barton, Ga.		Hanover, Penn.	
	Stone.	Lime.	Stone.	Lime.	Stone.	Lime.	Stone.	Lime.
Calcium carbonate	55.70	......	99.16	1.50	56.02	......	88.12	......
Magnesium carbonate	41.97	......	0.75	0.56	38.43	......	8.23	......
Oxide of iron and alumina	0.72	1.35	Trace	0.26	1.50	1.236	0.08	0.08
Silica and silicates	1 58	2.95	0.15	0.37	1.94	7.252	0.68	0.58
Moisture	......	......	......	......	......	1.622	......	......
Calcium oxide	......	58.33	......	97.30	......	34.070	......	92.00
Magnesium oxide	......	37.37	......	......	......	55.736	......	3.55
Potassium carbonate	......	......	......	......	......	......	......	4.23
Miscellaneous	......	......	......	......	......	......	7.43	......
Total	99.97	100.00	100.06	99.99	97.89	99.916	99.44	100.34

Table No. 7 gives the composition of limestone from different localities.

TABLE No. 7.

	Calcium Carbonate.	Magnesium Carbonate.	Oxide of Iron and Aluminum.	Silica and Silicates.	Insoluble.	Undetermined.	Organic Matter and Loss.	Calcium Oxide.	Magnesium Oxide.	Carbon Dioxide.
Howard Co., Md	77.83	3.19	5.15	......	13.60	0.24	......	......	......	......
Bayport, Mich	91.538	.944	1.834	3.33	......	......	2.854	......	......	......
Hannibal, Mo	98.80	.02	0 40	.08	......	......	......	......	......	......
Ulster Co., New York	97.00	......	0.40	2.60	......	......	......	......	......	......
Youngstown, Ohio	95.30	......	1.25	3.62	......	......	......	......	......	......
Natural Bridge, N. Y.*	......	......	0.24	0.24	......	......	......	22.43	29.48	47.73
Vernon, N. J	52.45	43.25	1.34	2.28	5.45†	0.35‡	......	......	......	......
Columbus, Ohio	93.21	4.70	1.74	......	......	......	......	......	......	......
West Winfield, Penn	95.10	1.12	1.00	2.78	......	......	......	......	......	......
Lannon, Wis	52.29	42.27	1.68	3.96	......	......	......	......	......	......
Calumet Co., Wis	55.09	43.96	.36	.59	......	......	......	......	......	......
Riverton, Va	98.29	.462	.167	.538	......	......	.578	......	......	......

* Dolomite. † Alumina. ‡ Phosphorus.

In five samples of Missouri limestone the calcium carbonate averaged 99.2%.

Limestones tested by General Gillmore for crushing strength varied from 3450 to 25,000 lbs. per square inch.

CHAPTER III.

ASPHALT.

ASPHALT or bitumen under some name has been in use for many ages. The terms have been used so much synonymously as well as interchangeably that it is often difficult to tell just what varieties are referred to. The practice is still kept up to a certain extent, some authorities speaking of asphalt, others of asphaltum, and some of both, while all are practically referring to the same substance. Some specifications have mentioned pure asphaltum. It would be extremely difficult to establish legally what pure asphaltum is. As one writer has said, asphalt is an occurrence and not a distinct substance.

In America natural bituminous pavements are called *asphalt;* in France, *asphalte comprimé;* in Germany, *Stampf-Asphaltum;* and in England, *asphalte.*

In the English translation of the Bible it is stated that Noah was told to pitch the ark with pitch; and in another chapter in Genesis, that when the tower of Babel was built slime was used for mortar; and in Exodus, that the ark of bulrushes in which Moses was found was daubed with slime and pitch. In each of these cases the Latin version renders the words "slime" and "pitch" as "bitumen" except in the case of Moses' ark, both words being used in the same sentence; "pitch" is rendered *pice,* the ablative form of *pix.*

In the Greek version these words are all rendered *ἄσφαλτος,* or from the same root except as above in Exodus, where *ασφαλτοπίσση* is used. This latter word is said by Liddell and Scott to be the same as *πισσασφαλτος,* which means a compound of asphalt and pitch. Riddell and White define bitumen as "A kind of asphaltum, Jew's pitch, or fossil tar," and add that it was

frequently found in Palestine and Babylon. Bitumen, they say, is from the Hebrew word *chemar,* and ασφαλτος from two Hebrew words meaning "mud."

Liddell and Scott also say that the belief that ἄσφαλτος is derived from σφάλλω is erroneous.

It is also stated in profane history that bitumen was used in building the hanging gardens of Babylon, and in other works of masonry construction in both Babylon and Nineveh. It was also used in making cisterns water-tight. Tradition says that this pitch came from the springs of Oyen Hit on the Euphrates.

In the light of all this it is safe to say that some forms of bitumen have been known to, and used by, the human race from very early periods. In some sections of Europe examples of masonry constructed with a bituminous cement are still extant.

Before proceeding to an extended discussion of bitumen in any of its forms, it will be fitting to examine the various definitions that have been given to it by different writers and students.

Whatever form is studied, it must be understood that bitumen is the essential base of all, and that will be considered first.

Prof. Sadtler says: "The word bitumen in mineralogy is applied to hydrocarbon mixtures of mineral occurrence, whether solid, liquid, or gaseous."

Mr. A. W. Dow, formerly Inspector of Asphalt and Cements, Washington, defines bitumen as "Any and all hydrocarbons, whether natural or artificial, soluble in carbon bisulphide."

Leon Malo, an eminent French writer on the subject, says in 1861 he made the following definition, and in 1897 he can do no better than to reiterate it: "Bitumen or pitch, the materials which impregnate asphalte."

Dana defines "Aspnaltum or mineral pitch is a mixture of different hydrocarbons, part of which are oxygenated."

Richardson: "Asphalt may therefore be defined as any hard bitumen, composed of saturated or unsaturated hydrocarbons and their derivatives, which melts upon the application of heat to a viscous liquid."

Mr. Dow defines both asphaltum and asphalt:

"Asphaltum—A natural bitumen, all or a portion of which is soluble in petroleum naphtha, and in most cases found associated with various mineral and organic substances."

"Asphalt—Any and all natural deposits containing asphaltum."

An unknown writer: "Asphalt is a compact bitumen, a product of the decomposition of vegetable matter, consisting mainly of hydrocarbons with variable quantities of oxygen and nitrogen."

Leon Malo: "Asphalte—Calcareous rock impregnated naturally by bitumen or pitch."

These different definitions from these different investigators have been given in order that it may be clearly seen in what respect the people who are studying the questions to-day, and who are probably as conversant with the subjects as any one in the world, differ, and in what they agree.

The great difference between the definitions of Leon Malo and the American writers will be noticed. According to him, nothing but what is known in this country as "rock asphalt" can be considered under that name. As a matter of fact, all asphalt pavements laid in the American manner are called artificial pavements in Europe. That is, the paving material must be formed by nature in order to constitute a real asphalt pavement.

The American definitions are very much alike in essential points, except that Mr. Dow uses and defines "asphaltum" and "asphalt." There does not seem to be any necessity for considering an intermediate substance between bitumen and asphalt. Neither does there seem to be any reason why some writers should use "asphaltum" and others "asphalt" when referring to exactly the same substance. Asphalt, being shorter and the more nearly English in form, will be adopted for use in this work.

A careful study of the foregoing definitions would suggest a combination of some of them by which the ideas of the writers might be incorporated together, with a result that might be more satisfactory than any one alone.

It does not seem necessary in a definition to give all the constituents of a substance nor all its properties, but sufficient only to render it easily recognized. It would seem, therefore, that a

definition might be reached by combining some of the ideas herein given that would satisfy all scientific requirements and not be too long. This then is suggested: Bitumen—Any mixture of hydrocarbons and their derivatives of mineral occurrence, whether solid, liquid, or gaseous, which is soluble in chloroform or similar solvents.

It may be of interest to state here that natural gas has been declared to be a bitumen by the United States Supreme Court.

The Buffalo Gas and Fuel Co. brought natural gas from Canada by means of pipes laid under the Niagara River. The customs officials sought to collect an import duty upon it. The case went to the Supreme Court, and in a decision rendered January 3, 1899, natural gas was declared to be a crude bitumen and entitled to be admitted free of duty.

Admitting the foregoing definition for bitumen, the one that follows, and it would seem naturally, is: Asphalt—Any hard natural bitumen, or any deposit containing such bitumen in appreciable quantities.

Any asphalt which has any distinctive feature about it can be qualified by the characteristic adjective, such as rock asphalt when the deposit is rock impregnated with bitumen, thus doing away with a multiplicity of terms and making each one self-explanatory.

In considering the origin of asphalt, or rather of the bitumen composing it, attention must be given to the petroleums, as the different authorities generally agree as to the direct production of asphalt from petroleum.

Prof. Wurtz says that asphalt is probably formed by the gradual oxidation of petroleum-oil. Dana states that petroleum passes by insensible gradations into pitt asphalt or maltha (viscid bitumen), and the latter as insensibly into asphalt or solid bitumen.

A German writer gives the following as his theory:

"In the oldest of the stratified rocks are found remains of the eozoon, the animal of the dawn of creation, a member of the infusoria. This division of nature is made up of diatoms and protozoa. The diatoms have two shells. These shells are composed of silica and pure quartz; inside the shell is the living thing which consists of a single cell of protoplasm. Throughout this plasm-

mass are scattered globules of fat or oils. When the plasm leaves its shell, the latter, being composed of quartz, sinks to the bottom and is preserved.

"The protozoa members of the infusoria are less regular in shape than the diatoms. They consist of a protoplasm-cell and generally have a shell of quartz or calcium carbonate. The protoplasm-matter of these animals also contains oil-globules scattered throughout the mass. The great chalk formations of the earth are made entirely of the remains of some of the protozoa. The ooze at present being deposited on the floor of the Atlantic is composed entirely of protozoa, the greater part being carbonate of lime, about ten per cent being similar to the infusorial earth found in the island of Barbadoes.

"In the West Indies and in California wherever asphalt is found, there also exist large deposits of marine infusorial earth. What is more natural than to suppose that the vast quantities of diatoms and protozoa have left their bony skeletons as infusorial earth, have yielded up their organic matter, and especially their contained oil-globules, to the formation of asphalt?

"The chemical elements contained in protoplasm are identical with those composing asphalt, although they do not exist in the same proportions.

"Recently two substances have been derived from asphalt that have been obtained hitherto only by the distillation of animal remains. And by the heating of fish-oils under pressure, chemists have been able to produce the members of the paraffine series."

Leon Malo admits that at some indeterminate epoch considerable masses of vegetables or animals buried in sedimentary beds, and heated either directly by the central heat or by the invasion of volcanic currents, have in an immense distillation given birth to all the bitumens. It is certain that this gigantic action was exercised in a very varied manner, according to place, temperature, pressure, the nature of the neighboring rocks, the epoch of its operation, and the original material, the product differing in form, appearance, composition, and properties. But the mode of formation has been the same throughout, and the resulting bodies contain an identical principle, the bituminous principle, which does not resemble any other body and for which it is not to be mistaken.

Peckham, reviewing the above, says that this view of the origin of bitumen, while very near the truth, is founded upon conjecture rather than proof, and has led to an assumed identity among all forms of bitumen that has enthroned error and discouraged research, with results that have been altogether unfortunate.

Dolphus Torrey, a chemist who has given many years to examinations of and experiments with bitumens in their various forms, writes that there is a tendency to assign the origin of petroleum, ozokonite, or mineral wax, and asphalt to an animal origin more widely entertained than ever before. It is difficult to imagine any other origin for these materials as found in many large deposits, and in all deposits which are productive on a commercial scale the conditions are consistent with the theory of animal origin. The theory of distillation from coal and other vegetable deposits to account for petroleum is beset with difficulties, while the conditions of such deposits admit our assuming the probable existence of animal life whenever vegetable growth was possible.

The mineral theories announced to account for the generation of petroleum appear to be without any basis of probability.

A correspondent of the *Engineering and Mining Journal* quotes from an article in the Austrian *Zeitschrift für Berg- und Hüttenwesen* as follows: "It has been urged that the absence of nitrogen in petroleum must be fatal to the theory of its animal origin, because an oil produced from animal substances could not fail to be nitrogenous. One answer to this argument was furnished when Dr. Engler actually produced from blubber and other animal fats an artificial petroleum free from nitrogen, as might have been expected, since the fats are non-nitrogenous. And Engler declares that the absence of nitrogen in natural petroleum is a necessary result of its production from animal remains, because the nitrogenous flesh decays rapidly and assumes soluble forms, so that it would be removed before the fat, which is peculiarly stable, began to be transformed by the slower process of dry distillation."

This proposition was confirmed by Dr. M. Albrecht, who treated several thousand mussels and fishes in this way and

found that the ammonia and nitrogenous bases incidentally produced were easily removed by reason of their extreme solubility in water.

Farther on, in speaking of the report made by Gumbel upon the samples taken from the sea-bottom during the voyage of the Gazelle, the above correspondent continues: "In samples taken from depths of 500 metres and over, fine globules of fat were found similar in character to adipocene sometimes found in ancient graves, or the fat still remaining in fossil bones. Director Gumbel recognizes the possible significance of this discovery in connection with the origin of petroleum."

Prof. Wm. C. Day of the U. S. Geological Survey details an experiment in relation to this subject. He says introductorily: "As a result of considerable experimental work in the last few years with asphalt from a variety of sources in the United States, together with a study of literature pertaining to the origin of bitumens from both the geological and the chemical standpoint, I became impressed with the belief that the solid and also some of the higher boiling liquid bitumens have been formed in the earth by the distillation of mixed animal and vegetable material together with steam at high temperatures, but at pressures that may or may not have been high."

Mr. Day placed a number of fresh herring, a quantity of pine sawdust, and a number of pieces of fat pine wood in a cylindrical iron retort and distilled it. Of the result he says that, on cooling, the contents of the bulb became a black brittle solid, showing a very pronounced resemblance to gilsonite in every way, with the following properties: black, glistening color, becoming brown on pulverizing and slightly darker than gilsonite; fracture conchoidal, entirely soluble in carbon bisulphide; 90.6 per cent soluble in ether, 66.3 per cent in alcohol, and 61.1 per cent in petroleum ether. As the distilling bulb cracked before it had been intended to stop the distillation, another trial similar to the above was made, except that the heating was continued longer. Of the second result he says that he obtained a substance so much like gilsonite that it was difficult to tell one from the other.

A combustion of the first samples gave carbon 87.5 and hy-

drogen 7.7 per cent; and of the second 88.9 per cent carbon and 6.7 hydrogen. The figures for Utah gilsonite are 88.3 per cent for carbon and 9.9 per cent for hydrogen.

He continues by declaring that the distillation of fish alone, without the wood mixture, gave nothing like gilsonite, and the distillation products were totally unlike in every way from those obtained by the mixing of fish and wood.

In 1860 Messrs. Wall and Sawkins made a report on the geology of the island of Trinidad, in which they describe at length the pitch lake and the attending phenomena. They call the deposit "asphaltum," and ascribe to it a vegetable origin. They contend that the only substances that contain sufficient carbon and hydrogen for the formation of asphalt are animal and vegetable remains. The latter are particularly abundant at La Brea, where most of the asphaltic beds have been originally carbonaceous and lignitic shales. They found what they considered to be specimens showing every stage of transformation from the first deposit to the total obliteration of organic structure, when nothing but the external form of the wood was left. After detailing some other observations they say: "These circumstances conduct us to the proposition that the bituminous substances of La Brea, whether fluid or solid, have been formed from vegetable material by direct conversion at the ordinary temperature."

The change is thus described: "The first department of the process consists in the formation of a black oily substance similar to what arises in a liquid form at the surface, and has been termed asphaltic oil. This may not be invariably the case, but has been frequently noticed particularly with respect to ligneous masses as distinguished from leaves and fragments. There is a constant endeavor on the part of this fluid to escape from the material in which it was formed. Some specimens of wood in the earliest stages of conversion continued to discharge oil for several months after being placed in the museum of the Survey at Port of Spain."

They also found pieces of wood that had accidentally fallen into the asphalt and been partially transformed. Also specimens that they thought were derived from leaves that had been blown upon the lake.

They say that while the process of transformation over the

La Brea district has generally ceased, there is sufficient activity to indicate clearly the source of material and the manner of development.

In commenting on the above theory, Richardson says that excavations made at the pitch lake since the report of Wall and Sawkins do not confirm their deductions: that, on the contrary, the deposits show no signs of conversion of vegetable matter into bitumen, and that their origin has been largely a mere infiltration of the soil of the bitumen already formed and which has subsequently changed in its chemical nature under the existing conditions.

A large proportion of the bitumen has undoubtedly come from the lake, and another portion has been forced up from below in a quite liquid state in much the same way as is seen at the soft spot in the lake. He does not believe, therefore, that the bituminous substances at La Brea have been formed from vegetable material by direct conversion at ordinary temperatures.

He states that asphalt is being formed now, not as a primary but as a secondary product, resulting from the transformation of lighter forms of bitumen, maltha, or even thinner oils into harder bitumen by condensation and polymerization—a reaction in which sulphur seems to take an important part.

Peckham declares that when he visited the lake he looked in vain for any wood in process of formation into asphalt; that he inquired of many people connected with mining the pitch, and could find no one who had ever seen any. On the contrary, one man told him that the wood never decayed in the pitch; another, that if it went in rotten it came out rotten.

Prof. Moissan attributes the origin of petroleum to metallic carbides, because carbides produce different hydrocarbons on contact with water: carbide of aluminum producing methane; carbide of calcium, acetylene; and carbide of uranium, a mixture of hydrogen, methane, and ethylene.

Mendelejeff's theory is that, after admitting the existence of metallic carbides, it is easy to find an explanation not only for the origin of petroleum, but also for the manner of its appearance in the places where the terrestrial strata at the time of their elevation into mountain-chains ought to be filled with crevices to their centre. These crevices have admitted water to the metallic car-

bides. The action of the water upon these carbides at an elevated temperature and under a high pressure has generated metallic oxides and saturated hydrocarbons which, being transposed by aqueous vapor, have reached those strata where they would easily condense and impregnate beds of sandstone.

Prof. Wurtz in his "Chemical Technology" says that, according to some, the formation of petroleum is intimately connected with the occurrence of hydrocarbons met with (according to the observations of Dumas, H. Roe, and Bunsen) in compressed condition in many rock-salt deposits, from which they are set free either in the state of gas or as naphtha when the salt comes into contact with the water or is broken up.

In his article on petroleum in the Tenth Census Report, Prof. Peckham, in speaking of bitumen and of the speculations that had proceeded along several quite different lines of investigation, says:

"Generally speaking they fall into the different categories embracing those who regard bitumen as a distillate produced by natural causes, those who regard bitumen as indigenous to the rocks in which it is produced, and those who regard bitumen as a product of chemical action."

After an exhaustive examination of the subject he concludes: "I am convinced that all bitumens in their present condition have originally been derived from animal or vegetable remains, but that the manner of their derivation has not been uniform."

He thinks the bitumens of California and Texas are undoubtedly indigenous to the shales from which they issue, and says:

"In Ventura County the petroleum is primarily held in strata of shale, from which it issues as petroleum or maltha, according as the shales have been brought into contact with the atmosphere. The asphalt is produced by further exposure after the bitumen has reached the surface."

He continues: "The exceedingly unstable character of these petroleums, considered in connection with the amount of nitrogen that they contain and the vast accumulation of animal remains in the strata from which they issue, together with the fact that the fresh oils soon become filled with the larvæ of insects to such an

extent that pools of petroleum become pools of maggots, all lend support to the theory that the oils are of animal origin."

After considering the petroleums of New York, Pennsylvania, Ohio, and West Virginia, he concludes that they are distillates of vegetable origin.

A careful study of these theories will demonstrate how much and how materially some of them differ from each other, as well as how satisfied the authors are that they are right in their conjectures.

It will be noticed, too, that all the American writers, men who have investigated the subject in recent years from a practical as well as a scientific standpoint, seem to agree that bitumen must have had its origin in some organic matter, either animal or vegetable.

The opinion of Prof. Peckham, a man who has been studying the question for so many years, who has visited so many of the asphalt fields, and has spent so much time in patient work in the laboratory, must carry great weight.

Bitumen belongs to that great group of hydrocarbons about which it is very difficult to give positive results. Chemists feel as if this group is a fertile field for experiment, but hesitate when asked to give positive information about any one of them. Until the last few years, their researches had mainly to be labors of love for the good of science as far as asphalt is concerned.

In 1837 Boussingault made some exhaustive analyses and examinations of Bechelbronn asphalt, and his conclusions were accepted for many years. He found this particular variety to be composed of:

	Per cent.
Carbon	85.90
Hydrogen	11.25
Oxygen	2.85
	100.00

He separated the bitumen into two parts which he called petrolene and asphaltene. Petrolene is a thick oily fluid, while asphaltene is hard and brittle. The former is the cementitious part of the bitumen and serves as a solvent to the hard asphaltene,

making the whole mass serviceable for pavements. The relative proportions of these two constituents in any bitumen are important. If it contain too much petrolene, the resulting mixture will be soft and sticky; while if the asphaltine be in excess, the mixture, while perhaps good when first laid, or in warm weather, would soon disintegrate and crack badly when the temperature became cold.

While bitumen is considered to be composed of these two substances, it must be distinctly understood that they are not definite chemical compounds, but occurrences in, or properties of, the bitumen. Boussingault did assign a chemical formula to them, $C_{20}H_{32}$ for petrolene and $C_{20}H_{32}O_3$ for asphaltene; that is, in the latter case the petrolene has become oxidized. Thomson, however, varied the above, making petrolene $C_{10}H_8$ and asphaltene $C_{10}H_8O_3$; and other chemists have arrived at still different results.

Chemists differ to some extent as to the methods and solvents to be used in extracting the bitumen from asphalt, and their determinations differ according to these means and methods. The amount of bitumen in a crude asphalt is not important as far as the character of the pavement is concerned, but commercially it is highly so, as upon the quantity depends the amonut of paving mixture that can be obtained from a given amount of the crude material.

At the present time, however, carbon bi-sulphide is the solvent generally used by chemists. After the amount of bitumen in an asphalt is known, its character must be determined. Different chemists make different determinations. Dr. Felix Kleeberg, Chemist for the Bureau of Highways, Borough of Manhattan, New York City, makes the following tests in the manner herein described:

Consistency.— The consistency or plasticity of bituminous materials is determined either by means of the Dow Penetration Machine or the New York Testing Laboratory Penetrometer. Both of these machines give results which are practically identical. The sample to be tested is placed in a seamless tin box and this placed in a bath of water, together with the glass container and kept for not less than thirty minutes at the temperature at which it is desired to obtain the penetration. When the penetration

is to be made the tin box and container covered with water from the bath are transferred to the shelf of the machine, the needle brought just in contact with the fresh surface and the dial reading taken. The needle is released for a period of 5 seconds and a new dial reading recorded. The difference in these readings is the degree of hardness at the temperature of observation. Great care must be taken to have the needle of standard size, the time and temperature accurate and that the tin box shall not be subject to any rocking motion, as a wide discrepancy in duplicate tests will be obtained.

Susceptibility to Changes in Temperature.—In order to determine the susceptibility to changes in temperature penetrations are taken as follows:

At 32° F. load for needle 200 grams, time 1 minute,

or

At 32° F. load for needle 200 grams, time 5 seconds,
At 50° F. load for needle 100 grams, time 5 seconds.
At 77° F. load for needle 100 grams, time 5 seconds.
At 100° F. load for needle 100 grams, time 5 seconds.
At 115° F. load for needle 50 grams, time 5 seconds.

Cohesiveness.—A measure of the cohesiveness of the material is obtained by means of the ductility test, using a brass mold of the Dow type. The bituminous material has a minimum cross-section of one square centimeter and having previously been brought to a temperature of 77° F. is drawn out at the rate of five centimeters per minute while immersed in water at 77° F.

Adhesiveness.—A brass briquette of the shape and dimensions of the standard Portland cement briquette with flattened ends cut in half and the ends corrugated is cemented together with the molten bituminous material, a weight of 4 pounds being applied until the cement is set. The briquette is then cooled for not less than ½ hour at a temperature of 40° F. and the number of pounds required for rupture determined.

Brittleness.—A steel ball weighing 1 ounce suspended by a movable electro-magnet attached to a graduated upright is permitted to drop upon a prism having a cross-section of ½ inch and a length of 3 inches suspended on knife edges, this prism of

bituminous material having been previously brought to a temperature of 40° F. The height at which the prism fractures measures the impact blow or brittleness of the material.

The test is carried out by pouring the molten bituminous material into a mold of proper dimensions, the sides of which

Fig. 1.

have been covered with a film of Venetian chalk to permit of ready removal from the mold. The prisms are then cooled to a temperature of 40° F. This temperature is readily obtained and maintained by ice and water. The prism is then placed on the knife edges and the approximate point at which the prism fractures is obtained in a preliminary test by rapidly increasing the height from which the ball is permitted to drop. Having obtained

an approximate idea of the point at which fracture will take place, this point is determined accurately with other prisms by increasing the height of the ball ½ inch at a time.

Specific Gravity.—In the determination of specific gravity different apparatus is used according to the nature of the materials. For liquids the hydrometer, picnometer or the Westphal balance is used. For solids a cube of the material suspended by hair or fine wire is weighed first in air, then in water, at 60° F., or this cube is placed in a salt solution at 60° F., which solution is adjusted so that the material neither sinks nor floats and the gravity of the salt solution is then obtained either with a picnometer or Westphal balance.

Volatilization Test.—This test is made in an electrically equipped oven the temperature of which can be adjusted by means of rheostats. The temperature is observed by means of two thermometers the bulb of one of which is immersed in a sample of non-volatile bitumen, while the other is kept in air at the same level. From 20 to 25 grams of the material is weighed out in a seamless tin box 2½ inches in diameter and ¾ inch deep, and the temperature as registered by the thermometer immersed in bitumen is maintained at 325° F. for a period of five hours. During this period the temperature should not vary more than plus or minus 2° F. The sample is then removed from the oven, allowed to cool and reweighed. The difference between this weight and the total weight before heating gives the loss by volatilization. The penetration test is made on the residue and compared with the penetration before heating.

Flash Test.—This test is made in a New York State Board of Health oil tester the bath of which is filled with paraffin. The oil cup is filled with the material to be tested to within three millimeters of the flange joining the cup and the vapor chamber above. The glass cover is then placed on the oil cup and the thermometer so adjusted that its bulb is 1 inch above the bottom of the cup. The small flame from a Bunsen burner should be applied in such a manner that the temperature of the material in the cup is raised at the rate of about 10° F. per minute. The testing flame is inserted in the opening in the cover to about half way between the surface of the material and the cover every

5° and when a faint bluish flame over the entire surface of the bitumen is observed the temperature is noted as the flash point of the material.

The burning-point may now be obtained by removing the glass cover and replacing the thermometer in a wire frame, raising the temperature at the same rate and testing the material as before. The temperature at which the material ignites and burns is taken as the burning-point.

Refined Asphalts and Asphaltic Cements.

Bitumen.—One to two grams of the carefully averaged sample is weighed out, placed in a previously dried hardened Schleicher & Schuell filter paper folded bag-shape and securely tied with a No. 25 silk-covered copper wire and extracted in a Soxhlet or Knorr extraction apparatus until the solvent (dry carbon bisulphide or chloroform as the case may be) is absolutely colorless. The filter paper is then dried at 100° C., the residue on the paper removed as completely as possilbe and weighed on a balanced watch glass. The solvent reduced to as small a bulk as practicable is then transferred, together with the filter paper, to a weighed platinum dish, ignited and the weight of the mineral matter thus obtained added to the weight of the material previously obtained. This latter weight represents the mineral matter plus the insoluble organic matter, and the difference between this weight and the original weight taken represents the bitumen.

Mineral Matter and Fixed Carbon.—One gram of the material is placed in a platinum crucible weighing from 20 to 30 grams and having a tightly fitting cover. It is then heated for 7 minutes over the flame of a Bunsen burner, which flame should be 20 centimeters high, and the determination is made in a place free from drafts. The crucible should be supported by a platinum triangle with the bottom from 6 to 8 centimeters above the top of the burner. The upper surface of the cover should burn clear but the under surface should remain covered with carbon. The crucible is then removed to a desiccator and when cooled is weighed, after which the cover is removed and the crucible is placed in an inclined position over the Bunsen burner and ignited until nothing

but ash remains. Any carbon deposited on the cover is also burned off. The weight of ash represents the amount of mineral matter in the material, and this is deducted from the weight of the residue after the first ignition of the sample, which weight is the so-called fixed carbon of the material.

Insoluble Organic Matter.—The mineral matter as obtained above subtracted from the combined weight of the insoluble organic matter, plus mineral matter obtained by extraction, gives the weight of the insoluble organic matter, or this may be reported as undetermined matter.

Carbenes.—One gram of material is weighed out in an Erlenmeyer flask about 200 c.c. of carbon tetro-chloride added and the flask protected from the light by placing in a dark closet. This determination should be started late in the afternoon and the next morning should be filtered through a weighed Gooch crucible, washed with carbon tetro-chloride, dried at 100° C. and weighed.

Analysis of Surface Mixtures.

Bitumen.—Ten grams of the carefully sampled mixture weighed out and placed in a hardened Schleisher & Schnell filter paper, the weight of which has been previously determined by drying to constant weight and weighing in a weighing bottle. The filter paper containing the weighed mixture is then tied with No. 25 silk-covered copper wire forming a bag which is placed in a Soxhlet or Knorr extraction apparatus until the solvent used (carbon bisulphide as a rule) returns absolutely colorless. The filter paper containing the mineral aggregate is then dried to constant weight at 100° C., allowed to cool in a desiccator, the wire removed and the weight obtained while in a balanced weighing bottle. In the meantime, the solvent, reduced to as small a bulk as practicable, is transferred to a weighed platinum dish, ignited, and the weight of the mineral matter thus obtained added to the weight previously obtained. The difference between this total weight and the 10 grams originally taken represents bitumen.

Grading of the Mineral Aggregate.

The apparatus used in determining the grading of the mineral aggregate consists of a motor-equipped agitator and sieves manufactured by Howard & Morse.

The mineral aggregate obtained above is carefully and completely removed from the filter paper and transferred to the top sieve of a set of eight sieves stacked in regular order, namely, 10, 20, 30, 40, 50, 80, 100 and 200-mesh sieve, the 200-mesh sieve resting on the pan. The sieves after being covered are firmly fastened in the rack and agitated for exactly 5 minutes. The contents of the sieves are emptied on glazed paper, the sieve carefully brushed and the contents weighed on a Chaslyn balance. Sand grading made by different operators where the above conditions are adhered to check up remarkably closely.

Voids.—The aggregate is thoroughly mixed and quartered if necessary until a representative sample of material more than sufficient to fill a section of a 4-inch steel pipe machined on the inside and cut to such a length that its cubical contents equal 1000 c.c. The pipe is set upright on glazed paper and the aggregate poured in a scoopful at a time and tamped continuously with the handle of a trowel. Care must be taken that no segregation of the material occurs either in scooping out or pouring into the pipe. The pipe is filled level full after which it is raised and the contents, which equal 1000 c.c., are allowed to remain in a pile on the paper. About 600 c.c. of water is placed in a 2000 c.c. graduated glass cylinder and an accurate rating of the volume taken. This is called a. The measured quantity of the aggregate is now poured in, a little at a time and stirred with a metal rod to displace any air bubbles. When all has been added and the dust has settled sufficiently to give a clear meniscus the volume is again read and this reading is called b. The percentage of voids may then be calculated from the following formula:

$$\text{Percentage of voids} = \frac{1000 - b + a}{10}.$$

Binder Mixture.

Bitumen.—Binder mixtures are analyzed by filling a weighed cylinder 1½ inches by 7 inches made of 200-mesh copper wire with the mixture. The sample is then submitted to the action of the solvent in an extractor of proper dimensions. When the bitumen has been extracted, the cylinder is removed, dried in an oven at 100° C., placed in a desiccator, cooled and re-weighed. The loss represents the bitumen soluble in carbon bisulphide.

Mineral Aggregate.—The solvent reduced to as small a bulk as practicable is transferred to a weighed platinum dish, ignited and the weight of the mineral matter passing the 200-mesh sieve thus obtained. The residue from the above extraction in the cylinder is then transferred to the agitator as in the case of surface mixtures, excepting that a 5-mesh sieve is added to the stack and the 200-mesh sieve removed.

In the New York Testing Laboratory, where probably more analyses of wearing surface are made during the course of a year than in any other laboratory in the country, Prof. Clifford Richardson uses the following method:

Ten grams of the surface mixture are weighed out in a glass tube, about 1 inch in exterior diameter and 8 inches long, and weighing from 50 to 60 grams. Carbon disulphide is added to reach to a height not greater than 4½ inches in the tube and amounting to 30–35 c.c. of solvent. The tubes thus prepared are placed in any satisfactory centrifugal and revolved at a rate of 1500 revolutions per minute for 15 minutes.

The tubes are then taken out and decanted carefully into an 8-ounce wide-mouth bottle labeled with a number identical with that of the tube, and after pouring off any sediment, more carbon disulphide is then added, the sediment thoroughly mixed with it by means of an iron rod, and the tubes again placed in the centrifugal and run for 10 minutes. The decanting is repeated into the correction bottle, more solvent added as before, and the tubes swung a third time. The third decantation usually leaves the residue free from any amount of bitumen which would influence the results. The tubes are placed in a warm spot to volatilize the remaining solvent and when dry are weighed. In the mean-

time the carbon disulphide solution is poured into a weighed dish, lighted and allowed to burn away in a hood with good draft. The residue of bitumen is burned in a muffle, and the remaining mineral matter added to that in the tube, either directly or as an addition to the weight of the tube. The loss of weight of the tube gives the percentage of bitumen in the surface mixture.

The centrifugal used when working on a large scale is a Troy laundry extractor or dryer, with a basket 30 inches in diameter, which has been filled about the circumference with solid boxwood, leaving an opening 11 inches in diameter in the center.

In this boxwood are bored about 3 dozen 1-inch holes to a depth of 6½ inches, sloping downward at an angle of 15°, provided with metal liners, in the bottom of which a piece of sponge is placed to form a cushion with water, and which in turn hold the glass tubes.

Any other form of centrifugal which will hold the tubes as described, or others of a similar capacity, is equally satisfactory. A power centrifugal holding six tubes and driven by electricity is furnished by the American Name Plate Company, 62 Sudbury Street, Boston, Mass.

Grading of the Mineral Aggregate.

The mineral aggregate after the tube has been weighed for the determination of bitumen, is carefully removed from it and emptied upon a 200 mesh. The particles of dust, which are caked together, are broken up by gentle pressure with the finger tips and the coarser sand grains thoroughly cleaned by attrition. When nothing further passes the seive the residue is transferred in any convenient way to the pan of a balance, preferably one which, while weighing accurately to a hundredth of a gram or $^1/_{10}$ per cent of the amount of surface mixture taken, does not require the use of weights but can be rapidly manipulated. With the balance the weight of the residue on the 200-mesh sieve is obtained and the difference between this and the weight of the mineral aggregate gives the percentage of 200-mesh material and filler in surface mixture. It is a determination by loss, and so no effort is necessary to save the dust which passes the sieve, unless it is desired to determine its chemical nature or subdivide further by elutriation when it should be caught in a closely fitting pan.

The other sieves are used in succession after the 200-mesh and the percentages passed by each determined.

The percentage of bitumen, dust, or filler, and various sized sand should amount to 100 per cent.

After an asphalt has been examined according to the above methods its characteristics are pretty thoroughly determined. If the material be an untried one it will be necessary to compare results of the different tests with similar results obtained by treating a standard asphalt in the same way. As it is the bitumen itself that is of value, a truer comparison is obtained by making the tests upon the extracted bitumen rather than upon the asphalts themselves, as asphalts may contain mineral matter which is not detrimental when used in a pavement but may affect the tests and therefore not permit of a fair comparison.

If carbon bisulphide be used as a solvent for the total bitumen, not only its temperature but its specific gravity must be specified. And if a new asphalt is being examined with a new supply of solvents, it will be safer to make a complete analysis of a well-known asphalt and compare these results with those obtained from the new specimen when the same materials were used. In this way reliable comparisons ought to be made.

The chemist does not confine himself to strictly chemical research. Asphalt in pavements is called upon to resist sudden and extreme changes of temperature ranging from 30° below zero to 140° above, as many of our cities have extremes of temperature of this amount. The effect upon the samples should be carefully noted at every 30°. These results will serve for comparison when the specimen under examination is given the same treatment, and in this way the probable relative values of the two asphalts determined as far as this one property is concerned. Pursuing the same method in relation to its absolute hardness, viscosity, etc., the worth of the new paving material for paving purposes can be pretty accurately determined.

It is doubtful, however, in the present stage of asphalt knowledge if any chemist would be willing to give a positive opinion upon the real value of any sample from any examination, whether chemical, mechanical, or both. It seems to be pretty generally accepted that the only sure way of determining the merits of a new asphalt

is by giving it a trial. This requires time and careful experiments, for a treatment giving good results with a bitumen from one locality may be very unsuccessful with another although the chemical properties may be very similar. The mechanical examination, if properly carried out, will throw much light upon this part of the investigations.

For some time chemists had considerable difficulty in distinguishing natural from artificial bitumen. They belong to the same hydrocarbon group and act similarly under solvents. Five years ago an expert chemist frankly admitted that chemically he could not tell if asphalt was adulterated with coal-tar, but it could be easily detected by its odor, and no appreciable adulteration could have taken place without its discovery if submitted to an expert.

In Thorpe's Dictionary of Applied Chemistry the following mode of procedure is laid down: "Native asphalt can be distinguished from artificial asphalt by extracting with carbon bisulphide, filtering, evaporating to dryness, and heating the residue until it can be ground to a dry powder; 0.1 gram is treated with 5 c.c. of fuming sulphuric acid for 24 hours and is then mixed with continuous stirring with 10 c.c. of water. If pitch or coal-tar be present, the solution will be of a dark-brown or blackish tint; if not, the solution will be of a light yellowish color." This method has been tried and found to be satisfactory when the amount of tar present in the asphalt was as small as 7 per cent, and without doubt would have been equally so had the quantity been even less.

Asphalt has been found in different forms widely scattered over the earth's surface.

In the Eastern Hemisphere the principal localities are Austria, France, Germany, Russia, Sicily, Switzerland, and Syria; in the Western, Cuba, Mexico, Trinidad, the United States, and Venezuela.

Of the above France, Germany, Sicily, and Switzerland furnish the rock asphalt used in the pavements of Europe, while the material for the American pavements comes from Trinidad, Venezuela, and the United States.

In the latter country asphalt occurs in California, Colorado, Indian Territory, Kentucky, Montana, Texas, and Utah, although all these deposits have not yet been used for pavements.

Trinidad Asphalt.

By far the most celebrated, if not wonderful, deposit of asphalt is that located upon the island of Trinidad. This island is situated off the coast of Venezuela, between 10° and 11° north latitude and in 61° west longitude. The principal cities are on the west coast, and the asphalt deposit is about 40 miles south of Port of Spain, the chief city, and adjoining the village of La Brea, the Spanish word for pitch. The houses of the village are built upon the asphalt, and on account of its motion it is not uncommon for a building that was erected on its proper lot to project years afterward upon that of its neighbor.

Approaching La Brea as it was in 1892, one saw asphalt piled about on various parts of the shore awaiting shipment. The pieces ranged from the size of a cocoanut to something over a cubic foot, and when any amount was left in the sun for several days it gradually melted and became once more an amorphous mass, requiring to be broken up before being handled.

The lake, as the Trinidad deposit is generally called, is about a mile from the shore and at an elevation of 138½ feet above the sea-level. The slope is gradual and very regular. The lake itself is the property of the Crown and has been leased to certain parties for a term of years, who alone have the right to remove any material from it. The village lots, however, and the land between the shore and the lake contain asphalt, and in 1892 a great quantity of it was being mined from these exterior localities. Much has been said by interested parties as to the origin of this external material. Whether it had its origin inside and is an overflow from the lake, or whether its appearance is due to the same causes as that of the lake, as well as the relative value of the two kinds, will not be discussed here.

Advancing up the slope to the main deposit, the appearance is much like the approach to a stone-quarry, asphalt taking the place of the stone, and tropical vegetation being seen instead of the hardy growths that cover our rocky hills.

In some places the pitch is at the surface, at others it is several feet below, with bushes and quite large trees growing upon it. The earth is removed and the asphalt dug with common picks to

depths of four or five feet. Water soon accumulates in these holes from the adjacent pitch. At the time of the visit spoken of there was nothing to determine the thickness of this outside deposit, as plenty of material could be obtained without excavating to any inconvenient depth. Upon gaining the top of the slope, and at the same time the edge of the lake, one experiences, at first glance, a tinge of disappointment, as nothing is seen to suggest a real lake. Instead the appearance is that of a morass with growths of grass, bushes, and small trees scattered over it. A large portion of the surface, however, is open, divided into irregular areas much like the back of an immense turtle, water being found in the dividing depressions.

The entire area has been accurately surveyed and determined, and it is approximately circular in shape, containing about 114 acres. Excepting at one place near the centre, the surface is hard, so that a horse and loaded cart can be easily driven over it. Near the centre it is so soft that a person walking into it will sink nearly up to his knees. This material can be gathered up in the hand, and on being squeezed water runs freely from it. The adhesiveness is such that the fingers are not materially soiled in the handling. This central mass is warm, not hot, and seems to be constantly disturbed. Sulphuretted hydrogen gas bubbles forth in small quantities.

At the time of the author's visit the material was being mined from the surface by hand with ordinary tools and loaded into carts and drawn to the shore by mules, and from there taken to the ships in the roadstead in lighters.

The pitch was excavated for a depth of a few feet as might be convenient, and the hole left while the work was pursued elsewhere. On account of the pressure below, or the action of the entire mass, these holes are filled in less than 48 hours, and in a few days the surface is as hard as ever. There is some testimony that the excavations outside of the lake proper will fill up in a similar manner in a longer time, but there was no visible evidence of it at that time.

In 1894 the concessionnaires built an iron pier far enough out into the gulf to allow steamers to come alongside. A railroad-track was built upon the surface of the lake and so constructed that

cars could be run by cable around the entire lake and, when loaded at any desired point, drawn to the initial station, where the body of the car is lifted from the trucks and conveyed by an overhead cable down to the water, out over the iron pier, and the material dumped into the hold of the vessel waiting to receive it. As illustrating some of the properties of this asphalt, it might be said that when this plant was first operated asphalt was the only fuel used for some time; also that the oil used for street-lighting in Port of Spain was manufactured from this material.

* In 1894 borings were made to determine the depth of the pitch. At the centre a depth of 135 feet was reached, still in pitch, but the movement of the mass prevented any further distance being attained. This depth was within 3½ feet of sea-level. On the north side of the lake, about 100 feet from the edge and 1000 feet from the centre, pitch of a uniform character was found for a depth of 75 feet. At 80 feet a few feet of sand was discovered, followed by more pitch to a depth of 90 feet. From there on to 150 feet the boring was in sand mixed with asphalt.

Similar borings made outside of the lake showed the latter formation near the surface, and on the south side, about 1300 feet from the centre, a hard asphaltic sandstone was encountered at a depth of about 80 feet. From these different observations it has been estimated that the asphalt has been deposited in an old crater some 2300 feet in diameter and over 135 feet deep, and amounts in quantity to about 9,000,000 tons.

From levels run in 1893 the centre of the lake was found to be at an elevation of 138.5 feet above sea-level and about one foot higher than the portion 1000 feet from the centre in an approximately northwesterly direction, from which point the surface rose six inches at the edge. The highest point is at the south side with an elevation of 141.4, and the lowest toward the west and north side, where it is about 138 feet above sea-level.

The surface is evidently lower than in former years, a natural condition when it is remembered that more than a million tons of asphalt have been removed from it. From the actual amount of the depression and the amount it should have been lowered by the output of the last thirty years, it has been figured by Mr.

* This description of the Pitch Lake is from Richardson's "On the Nature and Origin of Asphalt."

Richardson that there must have been an influx of new material of from 18,000 to 20,000 tons per year between 1893 and 1896.

The movement of the surface was shown by stakes set for running levels. These were driven every hundred feet for a distance of 600 feet from the centre. In three weeks' time the centre stake had moved 20.6 feet to the right and 12.2 feet ahead. The one showing the least motion to the right was at station 4, being 0.2 foot and 2.4 feet ahead, while at station 3 the stake had moved 1.7 feet but had kept its distance. The other stakes varied between these limits and that at the centre.

A mass of pitch containing vegetation was found in 1894 to have moved 5.5 feet laterally and 23 feet in line from the observed position in 1893.

TABLE NO. 8.

ANALYSES OF SAMPLES OF PITCH TAKEN AT DIFFERENT DISTANCES FROM THE CENTRE.

Feet from Centre.	Bitumen Soluble in Carbon Bisulphide.	Mineral Matter.	Organic Matter not Soluble.	Soluble in Naphtha.	Total Bitumen Soluble.
200	55.02	35.41	9.57	31.83	57.85
400	54.99	35.40	9.61	31.63	57.55
600	54.84	35.49	9.67	31.85	58.26
800	54.66	35.56	9 78	31.67	57.97
1000	54.78	35.44	9.78	31.58	57.64
1100	54.62	35.45	9.93	31.77	57.51
Average	54.92	35.46	9.72	31.72	57.79
1400	53.86	36.38	9.76	30.52	56.66

The above results were obtained by using hot carbon bisulphide and having each sample thoroughly dried before being treated.

The asphalt, as above described, is in a crude state and must be refined before being suitable for pavements. This work is generally done in this country at the most convenient seaport. The object of the refining is to evaporate the water, drive off the more volatile oils, and remove the coarser material. The process consists in heating the asphalt in large iron retorts to a temperature of about 400° F. for some five or six days, according to conditions. The foreign matter is allowed to settle to the bottom, and the remainder drawn off into barrels or boxes for shipment. The

sediment is then removed from the stills and used for some inferior purpose. The loss in refining is about 33 per cent, so that as a rule three tons of the crude material make two tons of the refined.

This was the first method adopted. But as a large portion of the foreign matter of Trinidad is silicious and, if taken out, will have to be replaced when a paving mixture is prepared, another process has been in use during the last few years. The apparatus consists of an iron retort sufficiently large to contain some 30 or 40 tons of crude material. In the inside is a continuous iron pipe arranged in gangs somewhat like a steam-radiator, having a return pipe to take the condensed water back to the boiler. Another set of pipes, called the live-steam pipes, has a direct boiler connection and a number of jets inserted in it at the bottom, so that the material in the retort can be kept hot and in constant agitation by the injection of hot steam through these pipes, thus insuring a complete and even mixture as well as more rapid evaporation. The retort being filled, steam is applied and the material heated to a temperature of about 300° F. After this treatment has been applied for about sixteen hours, the water is evaporated and the asphalt is ready for use or shipment. If this work is done near the mixing-plant, the flux is added before the product is drawn off and the asphaltic cement made without further apparatus.

This method is called the drying process, rather than refining, as the only change is the evaporation of the water.

The tariff on the crude being less than on the refined article, a test case was made with one cargo, and the final determination by the courts was that the asphalt treated as above must be considered as in a crude state.

The average of Richardson's analyses previously given for the dried asphalt is bitumen soluble in carbon bisulphide 54.92 per cent. Of this bitumen 70.12 per cent can be considered petrolene and 29.78 per cent asphaltene. Its specific gravity is about 1.38.

The entire amount of asphalt shipped from Trinidad since records have been kept has reached three and a half million tons, which should be equivalent to one hundred and thirty million square yards of asphalt pavement.

California Asphalt.

In the State of California bitumen can probably be found in more forms and more localities than in any other part of the world. It is said to exist there in all the intermediate stages between natural gas and the hard asphalt.

This has been known for many years. It was originally used by the natives in making their canoes water-tight. The early Spanish priests, the pioneers of civilization in that region, utilized it in constructing floors, roofs, reservoirs, and conduits. Later on, the Mexicans, following the example of the fathers, continued its use in practically the same manner.

But this was all local and was carried on in the sections near or adjacent to the deposits.

It was not till 1868 that any of the material was used for pavements, when in Santa Cruz an old wooden pavement was covered with bituminous rock. In 1876 more of it was used as an original pavement, and since that time its use has been extended to other cities in the Pacific States, and eventually all over the United States.

The forms of the bitumen adapted to pavements are maltha, asphalt, and bituminous rock.

Maltha is a thick viscous bitumen, flowing sluggishly at ordinary temperatures, but very freely when artificially heated. It contains a large amount of bitumen, of which a considerable percentage is petrolene. Its office is to serve as a flux for the asphalt. Its petrolene dissolves the asphaltene of the harder material and produces a mixture suitable for paving purposes, the amount to be used varying according to the composition of the ingredients and the results desired. Although deposits of maltha are found in many sections, the one of most commercial value is situated in Santa Barbara County, about 13 miles east of the city of Santa Barbara and on the shore of the Pacific Ocean. This deposit consists of a large body of bituminized sand covering an area of about 75 acres for a depth of 25 feet. The maltha is supposed to be supplied from a stratum of bituminous shale upon which the sand rests. The sand is covered with from 6 to 8 feet of surface loam which is washed off into the sea by a 12-inch stream of water under

pressure supplied by steam-pumps. A thin layer of clay resting directly upon the sand is then removed with spades. The sand is then loaded into cars with hot spades, drawn by a cable up an inclined way to the refinery, where it is dumped into a mixer consisting of a steam-jacketed cylinder in which revolving arms break up the lumps. The material then falls into vats of boiling water, the maltha floating, and the sand, sinking to the bottom, is carried away by mechanical means. The maltha flows from the surface of the water through a spout to a tank whence it is pumped into a storage tank of higher elevation. From there it runs into refining-kettles, where it is subjected for twenty-four hours to a heat of 100° F. at first, but finishing at 240° F. This removes all aqueous vapors and volatile oils, when the material is ready for use. The average composition of this product is:

	Per cent.
Bitumen	98.26
Mineral matter	1.74

The bitumen contains 94.13 per cent of petrolene. The specific gravity is 1.05.

Twelve miles west of Santa Barbara is located a deposit of asphalt proper. This covers an area of several hundred acres, and the material is mined in much the same manner as coal. The supply, as in the case of the maltha, seems to be from below. As the bottoms of the mines rise the asphalt is cut off, and in one drift the record shows that a total of 52 feet was cut from the floor in one year. This was at a depth of about 125 feet from the surface. The deposit extends out under the ocean, and from analyses it has been shown to be the same as that extending inland.

In appearance it is much like the refined Trinidad, though of less specific gravity. At a temperature of 70° F. it is hard and brittle, softening at 105° and melting at 248°. The crude material contains bitumen 59.15 per cent, organic matter 1.10 per cent, and mineral matter 39.75 per cent. Its specific gravity is 1.25.

It is refined in practically the same manner as the first method described for Trinidad, and is generally brought to a standard of 80 per cent bitumen for shipment.

Until 1900 practically all of the asphalt pavements had been laid with the natural asphalts, but as so much California oil was distilled for its more volatile products, and the final residue being asphalt (at least in name), it was thought that an asphalt suitable for paving purposes could be produced by a proper distillation of the oil, the California oil having an asphaltic base. Pavement laid with this material has been so successful that it is now an important industry in California.

In 1909 there were produced in that State 82,557 tons of oil asphalt, with a value of $926,848.00; and in 1910, 101,711 tons, with a value of $1,167,112.00; while in Texas there were produced, in 1909, 46,304 tons, with a value of $857,204.00, and in 1910, 57,713 tons, with a value of $1,040,825; this last State having come into the market as a producer of asphalt in the last five or six years. These two are the only States which produce an oil from which asphalt has been made. Oil asphalt, however, has also been manufactured from Mexican oils, and a recent deposit of oil has been found in Trinidad, which also produces a good asphalt. Great care, however, is necessary in the use of oil asphalt to see that the material is suitable for pavements. There is no question about this if the distillation has been properly made, and with a view to the production of an oil asphalt only. The by-products, however, of asphaltic oil distillation are so valuable that the temptation to exhaust the oil of its volatile constituents is often so great that the resulting asphalt is so hard and of such a character that is must be fluxed back, so that the character of the resulting asphaltic cement is not suitable for pavements. In the process, too, the material is often heated to such an extent as to render it unsuitable for pavements; so that asphalt of this character should be purchased of reliable dealers who manufacture the asphalt simply for paving purposes, and then careful tests should be made before the asphalt is used.

Bituminous rock, a kind of asphalt, was also produced in 1910 in the following quantities:

California	37,547	tons
Utah	5,110	"
Oklahoma	11,959	"
Kentucky	9,938	"
Total	64,554	"

Manufacturing Asphalt from California Asphaltic Petroleum

There are in the State of California four important centers of asphalt production, as follows:

1. The San Francisco Bay region.
2. Kern County at and near Bakersfield.
3. Los Angeles City and suburbs.
4. San Luis Obispo County at Hadley.

The annual asphalt output of the nearly thirty refineries engaged in the industry aggregates at the present time about 200,000 tons. About 3,500,000 bbls. of crude oil, or approximately $4\frac{1}{2}$ per cent of the State's total production, is used in the manufacture of asphalt. Local conditions influence the selection of the oils used, some of the smaller plants running only on oils between .935 and .955 specific gravity, from which the yield of asphalt may be as low as 25 per cent by weight. The additional revenue derived from the sale of the more valuable distillates obtainable from these oils is almost an economic necessity to insure profitable operation of the small plant. The larger and more important asphalt plants of the State (with one exception) use only crude oils of between .965 and .985 specific gravity. These heavier oils yields between 35 and 60 per cent of asphalt below 100 penetration, and produce no by-products of any value higher than that of the crude oil itself. For various well-known reasons a "dry oil" is chosen in preference to one containing water. All known methods of conveying oil to the refineries—pipe- lines, tank-cars, tank-steamers, and even tank-wagons — are utilized in the delivery of oil supplies, though the last named method is fast disappearing and is now used only occasionally by a few plants near the Los Angeles City oil field.

Oil freshly delivered is customarily stored in steel tanks where such free water in suspension as will settle out naturally

is allowed to gravitate to the bottom before the oil is conveyed to the stills. Plants using the heavier oils are further equipped with a pre-heating tank wherein the oil before passing to the stills is artificially heated by means of saturated steam from boiler or exhaust line in closed coils. This preheating raises the temperature of the oil to from 200° to 300° F. (according to the design of the coil and the source of steam) lowers the specific gravity of the oil and allows the precipitation of the greater proportion of any remaining suspended water.

The oil is then either pumped or gravitated to the stills, fires started with stills vented, and temperature gradually raised to and maintained at about 300° to 340° F. until all remaining water suspended in or emulsified with the oil is removed. The vents are then closed, fires slowly increased in intensity, and temperatures of oil gradually raised at the rate of from 30° to 50° F. per hour until a maximum of 600° to 700° F. is reached. The charge is then held at the determined maximum as closely as possible until the consistency of the residual asphalt, as indicated by chewing (or other approximate tests) has reached the desired point. Fine distinctions as to penetration are useless at this point because the consistency of the asphalt after leaving the still undergoes certain indeterminate alterations beyond the control of the refiner. The total time consumed in finishing a charge—or "running down"—varies with the character and condition of the crude oil, with the size of the still and with certain other factors of less importance, but is usually from 16 to 36 hours. The fires are now extinguished and the asphalt discharged by gravity through a line—usually 2 to 2½ inches diameter—into horizontal cylindrical closed steel kettles in which it is allowed to cool. When the temperature of the finished asphalt has reached a point between 210° and 250° F. the contents of each cooling kettle are run into wooden barrels, allowed to cool to air temperature and then warehoused or shipped. The usual practice is to stencil each barrel with lot or batch number and degree of penetration at 77° F. before warehousing in order to allow classification by penetration in storing the product.

Throughout the entire period of distillation the still-charge is kept agitated by steam jets for the purpose of preventing overheating of the oil in contact with the hot plates at the bottom of the still and also to assist in the liberation and removal of the vaporizable portions of the oil. The vapors are condensed in the ordinary way and the resulting distillates usually sold as "gas oil" or fuel, unless they contain naphthas of value, in which case they are subsequently redistilled and put into marketable condition.

The stills used in the industry are all of the common horizontal cylindrical type without internal flues. They range in dimensions from about 7 feet diameter by 18 feet long to 12 feet diameter by 30 feet long and in internal capacity from 125 bbls. to 600 bbls. of 42 gals. each. No stills of the "cheese-box" type are in use. To facilitate emptying each still is set with its longitudinal axis at a slight angle to the horizontal, the bottom inclined toward the discharge end at about $\frac{1}{8}$ to $\frac{1}{4}$ inch to the foot. About five-sixths of the total capacity of each still is considered a full charge of crude oil.

Each of the larger asphalt refineries operates from eight to sixteen stills. The quality of their product is under laboratory control, and the daily routine of tests includes determinations for degree of penetration, per cent soluble in carbon tetrachloride, per cent loss on heating 5 hours at 325° F., and per cent reduction in penetration due to heating.

Most of the smaller refineries attempt to operate without laboratory control. Their somewhat limited output finds its way largely into the roofing and pipe-dipping industries. Oxidation during the process of distillation is used to some extent for the purpose of reducing the susceptibility of the asphalt to temperature changes, but this system is not in general use because of the danger of over-oxidation to a degree at which the product possesses a very low ductility and too little cementing value.

The average of 100 barrels of mixed crude oils from Ventura County was as follows:

	Barrels.
Gasoline, 76° Beaumé	3
Benzine, 63° "	4
Kerosene, 45° "	15
Heavy kerosene, 38° to 40° Beaumé	8
Gas distillate, 28° "	21
Light lubricating-oil, 26° "	10
Neutral oil, 23° "	12
Heavy neutral oil, 21° "	6
Reduced-stock lubricating-oil, 14° Beaumé	5
Asphalt, crude	11
Loss	5
	100

In the western part of Kern County there are important deposits of asphalt. In some localities it is found on the surface, and in others as veins of asphalt in the mountain rock. The surface material was used at first with good results. In appearance it is very similar to that found near Santa Barbara. It lies in beds of from 6 inches to several feet in thickness, the purer material being on the top. In some places the deposit rests upon clean sand, and in others upon sand that is saturated with oil.

The vein of asphalt is found in a dike and consequently runs parallel with the mountain range, is covered with a soft brown rock which can be traced for several miles, indicating the existence of asphalt to that extent. The vein is from 3 to 15 feet in width, and is easily worked from shafts or by drifting.

In Santa Cruz, San Luis Obispo, and Monterey counties asphalt occurs of an entirely different nature. It is called bituminous rock, and consists of a natural mixture of bituminous oil and sand. It is found in large quantities with much variation in amount of contained bitumen. The sand is of all grades of fineness, sometimes mixed with clay and so hard as to be almost a sandstone. It makes a good pavement in its natural state when properly treated. The early asphalt pavements of California were laid with this material, and when the variation in amount of bitumen, as well as the ignorance of the industry at that time, is considered, the wonder is that so many good results were obtained, rather than that there were some failures. The material was simply softened by heating on

the street sufficiently to allow it to be smoothly and evenly rolled when it was laid on the slightly prepared surface. Doubtless a lack of proper foundation often caused a failure in an otherwise fairly good pavement.

The first street east of the Rocky Mountains paved with material from California was in South Omaha, Neb., in 1891.

European Asphalt.

The asphalts from Europe from which pavements are made are found in France, Germany, Switzerland, and in the island of Sicily. (In a pamphlet issued by a Greek professor in 1721 he says he discovered ten years before a mine of asphalt in the Val de Travers Canton, Neuchatel, Switzerland, similar to that existing in the valley of Siddim near Babylon.) Although somewhat widely separated, these asphalts are practically of the same nature, differing somewhat in amount of bitumen contained.

They are all bituminous limestones. They occur in strata of varying depths, from 6 to 23 feet in thickness, separated by impermeable beds of stone.

The theory of the formation is that at an early geological period bitumen must have been vaporized by extreme heat, that certain strata of the limestone were softer than others, and that this bituminous vapor was forced through and along the soft strata, as subterranean water follows any previous stratum confined by beds of clay or rock, and that fissures in the overlying strata have allowed the vapor to pass to other strata above. In passing, the vapor impregnated the particles of the soft limestone to a greater or less extent, and the geological changes in the subsequent years produced the rock asphalt as it exists to-day. Fig. 2 illustrates this formation.

Its composition is almost entirely carbonate of lime and bitumen. To make a good pavement, the rock should contain from 9 to 11 per cent bitumen. While this amount may not be found in just the required proportions in nature, it can be obtained by mixing a rock that is rich in bitumen with one containing less, so that the compound shall contain the percentage desired.

Published analyses of the same mine differ considerably, per-

haps on account of the solvents or methods used by the examining chemists, or possibly from an actual variation in samples from the same deposit.

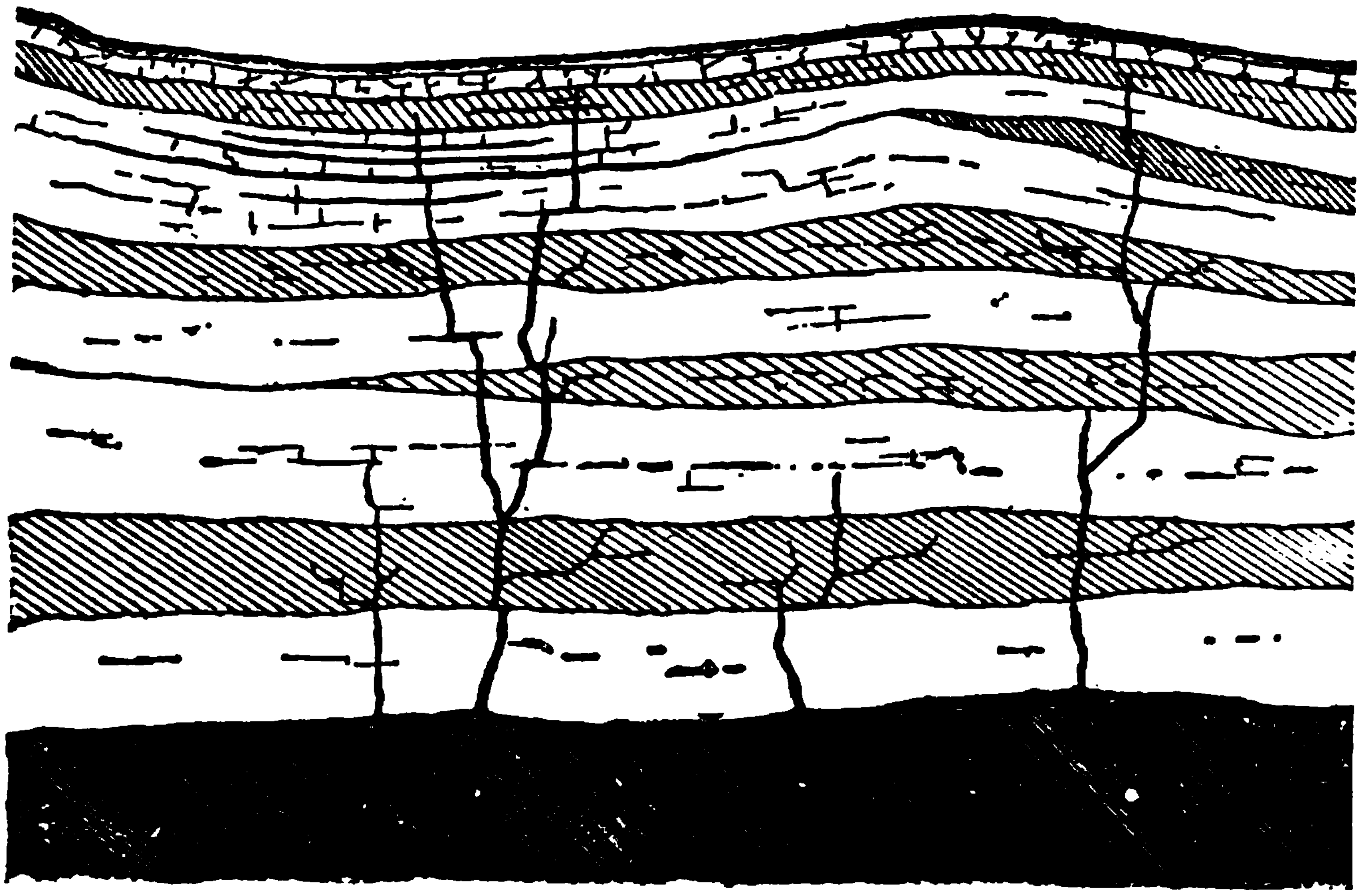


FIG. 2.—POSSIBLE FORMATION OF ROCK ASPHALT.

The following are some analyses collected from various authorities, the bitumen and calcium carbonate only being considered:

TABLE No. 9.

	Bitumen.	Carbonate of Lime.		Bitumen.	Carbonate of Lime.
Ragusa, Sicily.....	9.72	88.75	Val de Travers,		
	8.92	88.21	Switzerland.....	10.15	88.40
	8.85	87.50		12.00	
Seyssel, France....	9.10	90.35		7.00	
	8.15	91.30		12.44	61.76
	7.00	.....		10.10	87.95
	11.81	88.20	Vorvohle, Germany	5.35	90.80
	8.00	89.55	Limner, "	14.30	67.00
				8.26	56.54

Mexican Asphalt.

In the State of Vera Cruz, Mexico, there are fifteen separate deposits of asphalt; that is, there are fifteen places where asphalt is found at the surface.

Analyses of samples from the different localities show the material to be identical, and it is supposed that they are all connected underground, and supplied from the same source.

These deposits as found vary in width from 150 to 200 feet, and in length from 400 to 600 feet. The overflow from them is very great. In several instances it forms a bed between 50 and 60 feet wide and one or two miles long.

The largest deposit is known as Lake Chapapota, or in the language of the natives, Laguna Chapapota ("Lake of Asphalt"). This lake is of irregular shape and of unknown depth. Its sides are nearly perpendicular, as no bottom has been found by sounding three or four feet from the edge.

Large quantities of the material have overflowed in every direction, and whatever amount has yet been taken from the lake, the overflow still continues uninterruptedly. It has been estimated that 1000 tons per month could be taken continually from the lake without in the least lowering its surface. The amount in sight has been calculated at about 300,000 tons.

Pipes have been sunk to a depth of 500 feet near these deposits which have passed through vast beds of asphalt. From these pipes asphaltic oil is constantly flowing.

An analysis of nine different samples of this asphalt in a crude state gave results as follows:

TABLE No. 10.

Bitumen	84.04	82.74	86.34	83.70	87.94	86.11	90.14	87.54
Wood, insects, shells, and leaves	4.86	4.76	2.96	1.96	2.36	3.12	2.36	2.56
Matter volatile at 450°	11.10	12.50	10.70	14.70	9.70	10.77	7.50	9.90

The refined product analyzed:

	Per cent.
Bitumen	99.47
Silt and lime	.53
	100.00

The above analyses were made by Julius C. Schubert of New York, who recommended for a paving mixture:

	Per cent.
Bitumen	12
Carbonate of lime	15
Sand	73

An examination of another sample was made by Marriner & Hoskins of Chicago. The asphalt was heated until all the water was expelled, and then the temperature was gradually raised till the thermometer indicated 400° F. and maintained there for nine hours. The fluid was then poured from the sediment, of which there was but little, and analyzed:

Specific gravity at 60° F.	1.069
Bitumen soluble in ethyl ether	79.40
" " " petroleum ether	63.15
Residue " " turpentine	33.78
Undissolved organic matter	1.72
Ash	1.25

Physically,

at 60° it was tough, compressible, and flexible;
at 75° it was softer and more flexible;
at 100° it had the consistency of putty; beginning to flow;
at 300° there was no flash.

It is claimed for this asphalt that it requires the addition of no flux whatever to prepare the asphaltic cement, and that on this account, and because of its greater purity, it will resist successfully the action of air and water. Also it is said that a kettle of this material was heated to 625° F. for ten hours without its being damaged in the least. This last fact would avoid the liability to injury on account of overheated sand, which often occurs in using the asphalts at present in general use. This asphalt has never been used to any extent in the United States.

Bermudez Asphalt.

In the State of Bermudez in the northern part of Venezuela and about one hundred miles from the island of Trinidad is another large deposit of asphalt. It was discovered by the early explorers of this region, but no attempt was made to develop it or put it on the market until within the last few years. It is generally called a lake, and is situated near the San Juan River, about 30 miles in an air line from where it empties into the Gulf of Paria.

The river is navigable for vessels drawing 18 feet of water to this point, at which is situated the shipping station of the New York and Bermudez Company, which owns and controls the property.

The lake is about 5 miles from the point of shipment. It includes an area of some 900 or 1000 acres and is covered with quite a heavy growth of grass and bushes. Its depth has never been determined, as in sounding it has never been possible to find bottom, and the supply seems to be inexhaustible. In hardness it varies from the material that is in a soft fluid condition to the hard brittle glance pitch, but the greater part is of a medium grade suitable for commerce.

Through the lake runs a so-called stream of soft material, varying in width from 100 to 400 feet, seemingly in a state of continued motion.

Over all the surface except this stream one can walk with safety at all times of the day, but on the stream itself it is not safe to venture after the sun is a few hours high, as the heat soon renders it so soft that a man will sink into it to quite a considerable distance.

It is said that a workman dug day after day for two years in a hole about 6 feet in diameter, and the amount removed in the daytime would be replaced at night, so that the hole was no larger at the end of two years than at the beginning.

A narrow-gauge railroad, operated by steam, connects the lake with the shipping-point. The surface of the asphalt not being firm enough to sustain the weight of the steam-cars, a portable track is laid out on the lake upon which cars are operated by hand. The pitch is dumped from these hand-cars into those on the main line, which in turn are drawn down to and out upon the dock, when they are unloaded into vessels lying alongside.

The first pavement laid with this material was on Woodward Avenue, Detroit, in 1892. Since then, however, it has come into general use in the different cities of the country. The crude material is refined at South Amboy, N. J.

When refined, the asphalt contains of bitumen 95 per cent, the remainder being mineral and organic matter. The bitumen is

composed of petrolene 77.90 and asphaltene 22.10 per cent. The specific gravity is 1.08.

Kentucky Asphalt.*

This material is found in the Chester group of subcarboniferous rocks along the eastern and southern edge of the western coal-field of Kentucky. It also exists in the conglomerate sandstone of the coal-measure, but under heavy cover. Its principal localities are in Breckinridge, Grayson, Edmonson, and Logan counties.

The deposit is really a sandstone impregnated with bitumen. The rock is not found in distinct veins, but more in the shape of pockets of varying area, having a depth at the centre often of 10 feet. The material is mined by stripping off the overlying sandstone, leaving the bituminous rock exposed and ready for excavation. The stone is fine-grained and nearly all silica, carrying on an average some 8 per cent of bitumen, but at times as much as 12 per cent.

After the bitumen is extracted, the rock analyzes:

	Per cent.
Silica	96.88
Sesquioxide of iron	0.81
Alumina	0.46
Lime	0.34
Magnesia	0.20
Soda	0.81
Potash	0.20
Combined water and loss	0.25
	99.95

In preparing the rock for paving purposes it is first ground in mills consisting of horizontal plates to which raised lugs are attached revolving at a high rate of speed. The rock is broken by impact and carried by centrifugal force through a screen surrounding the mill. After leaving the mill and passing a second screen, the powder is borne by elevators to revolving heaters, where, after being raised to a proper temperature, it is taken to the street and laid in the usual manner. The entire operation of grinding and heating is automatic, the rock not being touched by hand from

* From a paper by Marshall Morris. Read before the St. Louis Engineers' Club.

the time it is placed in the elevators to be carried to the mills till it is delivered on the street. Care, however, is required in selecting the rock for the crushing so that the product may contain the required amount of bitumen when placed in the pavement.

Portions of two streets in Brooklyn, N. Y., were paved successfully with this material in 1889.

In 1890 a small amount was laid on a sidewalk at the wagon-entrance of the Adams Express Co. in Louisville, Ky. Since that time it has been used with good results in many other cities, but most extensively in Buffalo, N. Y., in conjunction with the German rock asphalts, and also in St. Louis, Mo. It has, however, been successfully used in combination with the limestone asphalts of Texas and Indian Territory.

The proportion generally recommended in connection with the foreign asphalts is:

	Per cent.
Kentucky rock	70 to 80
German "	30 to 20

Texas Asphalt.

The asphalt deposits of Texas are in Uvalde County. There are two areas of bituminous rock, one in the extreme western portion of the county along the courses of the Turkey, Gato, and Olmos creeks, and the other near the Nueces River near the Southern Pacific Railroad. The first-mentioned lies along these creeks in a continuous area about 4½ miles long north and south, and half a mile or more in width. The asphalt occurs as an impregnation of a porous limestone.

The principal mining is done at Carbonville, about 6 miles from the Cline station of the Southern Pacific Railroad. The quarries are easily worked, as there is very little overlying material to be removed. The rock is treated on the spot and is sold in two conditions, as a mastic and as a gum.

The mastic is prepared by grinding the rock to the required fineness, when it is melted and run into moulds, and when cool is ready for shipment. This product is used for pavements and is further treated by the addition of sand, residuum oil, etc., as may

be required at the place where it is to be laid. A portion of a street in Houston, Texas, has been paved with this material, and it has also been used to some extent in New York City.

The gum, however, is more valuable commercially. This is prepared by dissolving out the bitumen from the rock with benzine. The benzine is then distilled off and used over and over again with but little loss. The bitumen is obtained in an almost pure state.

Two different samples of the rock analyzed as follows:

	Per cent.
No. 1 bitumen	25.18
Organic matter	1.46
Mineral residue	73.36
	100.00

No. 2 bitumen extracted by petroleum naphtha (petrolene)	6.40
" " chloroform (asphaltene)	2.63
Total bitumen	9.03
Mineral residue	90.97
	100.00

The mineral residue was found to be carbonate of lime with an appreciable amount of oxide of iron and a trace of magnesia. Although the above samples show quite a difference in the amount of bitumen, the average is from 14 to 15 per cent.

Nueces River Deposits.

The bituminous rock in this locality is a sandstone. Its area extends from a point on the Nueces River about 9 miles below the Southern Pacific Railroad for more than 3 miles. Its width has not been determined. It outcrops in places along the river, and at Waxy Falls a stratum of sandstone bearing some bitumen was found 10 feet thick about 25 feet below the top of the bluff. Next below this is another stratum, 5 feet in thickness, containing so much bitumen that under the heat of the sun it oozes out over the surface.

Samples of rock taken from the outcrop near Waxy Falls upon analysis gave the following results:

	Per cent.
At the surface, bitumen	13.24
Two feet below the surface, bitumen	15.03
Sand	74.03
Oxides of iron and alumina	7.76
Organic matter, water and undetermined	3.18
	100.00
Four feet below the surface, bitumen	12.36

Utah Asphalt (Gilsonite).

Quite a deposit of bitumen of a very pure quality exists in the eastern part of Utah and the western portion of Colorado. It is called "Gilsonite" from Mr. S. H. Gilson of Salt Lake City. It is mined in the counties of Uintah and Wasatch, Utah and Clear Creek Co., Colorado.

Physically it is a black substance, quite hard and very brittle, breaking with a conchoidal fracture. It has a brilliant lustre and in appearance is much like glance pitch. It occurs in veins of from one-sixteenth of an inch to 18 feet in thickness, and sometimes extending a distance of 10 miles.

These veins were originally cracks in the rock which in some way have become filled with the gilsonite presumably at the same time the rupture occurred, as pieces of rock are frequently found entirely separated from the adjacent walls. The theory is that the gilsonite while in a plastic state was forced into the rock-fissure by some unknown force. No attempt has been made to explain the previous condition of the material.

There are six well-defined veins of this material, and the following estimate has been made of their contents:

	Tons.
Duchesne vein	941,916
Culmer vein	410,666
East and West Bonanzas	10,504,000
Cowboy vein	8,888,000
Black Dragon vein	3,000,000
	23,744,582

It is easily mined, as it yields readily to the common pick and breaks freely upon the rock, and requiring no sorting after a depth is reached below the influence of the atmosphere.

The above veins are from 100 to 200 miles from a railroad, and, on account of the roughness of the country, the transportation charges are heavy.

Gilsonite is used chiefly in the arts and manufactures, but it is sometimes added to other bitumens for paving mixtures.

It is wholly soluble in carbon bisulphide, and partially so in ordinary ether, alcohol, petroleum ether, and chloroform. Chemically it is composed of:

	Per cent.
Carbon	88.30
Hydrogen	9.96
Sulphur	1.32
Ash	0.10
Oxygen and nitrogen	0.32
	100.00

Since the above analysis was made, Prof. Day says that a further investigation shows the nitrogen to be 1.96 per cent, and he thinks the figures for hydrogen are correspondingly too high.

Bituminous limestone has also been found in Utah, but it has never been mined to any great extent.

Oklahoma Asphalt.

Murray County and Carter County in the State of Oklahoma contain some very extensive deposits of *asphaltic sand*, and limestone deposits fully saturated with soft bitumen. In Murray County, these deposits are located about three miles northeast of the village of Dougherty, and in Carter County, two districts have been developed, one about 5 miles southwest of the town at the foot of the Criner hills, and another about 20 miles north-of Ardmore, west of Ardmore, near the village of Woodford, at the base of the Arbuckle Mountains.

The largest deposits of bituminous lime rock are those near Dougherty and are said to be of such magnitude as to warrant the title "inexhaustible," and the same thing may be said of the deposits of asphaltic sand near the village of Woodford in Carter County. These deposits produce three different classes of material, which are briefly described as follows:

Bituminous Limestone.—The bituminous limestone or carbonate deposits consist of a vast bed of amorphous limestone interspersed with crystalline masses of calcite. The theory is that the entire mass was at some date cracked so that the infiltrating bitumen penetrated every part of it excepting the crystalline portions. The material, therefore, consists of an impregnated limestone containing a surplusage of bitumen in seams or cracks. The quarry face analyzes about 7 per cent of a soft bitumen and under pressure the mass breaks into thoroughly coated asphaltic stone particles, each particle of which is also thoroughly saturated with bitumen.

This asphalt limestone grinds easily into a fine powder which furnishes a bituminous filler for paving purposes, and the unpulverized pieces of stone form a reinforcing material for asphalt pavements.

Sand Deposits Containing Solid Bitumen.—The deposits of asphaltic sand located south of Ardmore near the Criner hills consists of beds of sand graded from 100 mesh to 60 mesh, the principal parts of some deposits being 100-mesh sand and of others 80-mesh sand, and very few containing coarser sand. Bitumen extracted from these deposits has a penetration of approximately 27, so that this product requires fluxing before it is suitable for paving purposes.

Sand Deposits Containing Soft Bitumen.—Very large deposits of this character are found near the village of Woodford. The bitumen is so soft as to have no penetration, the needle passing through the asphalt without resistance. This material has an application in the paving industry as a fluxing agent.

From these three asphalt rocks a pavement is made which has been laid very extensively in Kansas, Texas and Oklahoma. The theory is not dissimilar to that of the ordinary sheet asphalt pavement, for the bituminous limestone furnishes a filler with its own asphalt. One of the asphaltic sands furnishes sand with its own solid bitumen or flux. These rocks are pulverized and mixed thoroughly in their heated state, and the contained bitumen tempers one another to a proper consistency. The result is a pavement having a good sand grading and high proportion of limestone filler, and an asphalt cement made entirely of native

mineral bitumen without any residuum oil or other adulterations.

This pavement has been subjected to heavy traffic on streets having an average of five thousand collars per day, and has stood up under this traffic for about four years without any perceptible wear or deterioration.

The pavement is usually laid directly upon a concrete base without any binder course, the thickness being about 2 inches.

From these same deposits the rock bitumen is being extracted, and where prohibitive freight rates exist the same form of pavement is being built by shipping only the bituminous limestone and manufacturing the sand aggregate to go with it, using in said manufacture local sand and the native rock bitumen. It is reported that this system is reproducing all of the qualities of the original pavements, while it does away with two-thirds of freight charge. Heretofore this pavement could not be transported for a greater distance than 500 miles from the quarries, but the latter system will allow the application of this material to all parts of the United States at a cost very little, if any, in excess of ordinary sheet asphalt pavements.

There is some similarity in this industry and method to the use of the continental asphalt rocks, which are so largely used for the paving in Europe, but the materials and the product are much different, for the sand aggregate produces a silica surface which is not slippery and the materials considered separately are of different construction from the European asphalt rocks.

Montana Asphalt.

A deposit of bitumen generally termed asphalt, but not strictly so under the definition previously given in this chapter, is found in Montana. At ordinary temperatures it is soft and will pour slowly. Upon being treated with carbon bisulphide, 95 per cent was dissolved. Treated with gasolene 80 per cent was found to be petrolene, the insoluble matter in both cases being leaves, feathers, bugs, flies and other insects. The deposit has never been developed commercially.

Cuban Asphalt.

On the island of Cuba there are a large number of deposits of various kinds of asphalts and other native bitumens, some of which were of commercial importance during the early days of paving industry. Pavements were laid at an early date in the City of Washington, D. C., with asphalt from Cuba.

Practically the only deposit on the island, which is of large extent and not characterized by occurrence in small pockets, is the Mariel deposit located in Pinar del Rio province, about 40 miles west of Havana and about 5 miles from Mariel Bay, from which the deposit takes its name. Although the deposit is of very large extent, this fact does not appear to be well known, and possibly for this reason there has been no description or account of the deposit given in engineering literature.

The asphalt of these Mariel deposits is a comparatively hard material and is mined and handled like coal. The asphalt occurs in immense seams and veins, some of which may be followed by their outcroppings for several miles across the country. There are a number of Maltha or tar springs located adjacent to some of the veins, but unlike certain other deposits of natural asphaltum these tar springs appear to have no relation with the asphalt now in place. The veins or seams of asphalt lie horizontally in certain instances and have been worked by open cuts following the seams to a convenient depth. At other points of outcroppings the material has been obtruded in a vertical direction, and the excavation of open pits has followed the trend of the crude material downward. Certain of these pits have been excavated to a depth of approximately 250 feet from a 200-foot opening on the surface. These vertical obtrusions of asphalt narrow at certain points, giving indications of pinching out, but in all cases further excavation has revealed the fact that the veins widen as the depth increases, until finally the cost of timbering, the pumping of water, and widening of the veins necessitates further operations by driving large galleries into the masses of the deposit. So far as can be ascertained the total depth of these veins has never been determined, but the widening of the various cuts and excavations as they were pushed to greater depth, suggests the possi-

bility that at sufficient depth they would run together in a mother lode. It has been impossible to determine the quantities of asphalt in the deposit further than the fact that the amount is very large and that several millions of tons are in sight. Undoubtedly the deposit will yield much of scientific interest as it is more fully uncovered and studied.

Crude asphalt from the mines is loaded into box cars and transported by narrow gauge railway to Mariel Bay, where it is loaded upon steamers and brought to England or the United States. The asphalt used in the United States is taken to Mobile, where large refineries are maintained for preparation of the material for the market. A smaller refinery is located in Chicago for the preparation of refined asphalts and various compounds for local use.

The crude Cuban asphalt as it comes from the deposit is a comparatively hard substance containing a small amount of moisture and about 40 per cent of mineral matter. Like the Trinidad crude material there is a remarkable uniformity in the proximate composition of the material from the different parts of the deposit. Although, of course, the crude Cuban asphalt is not emulsified with water as is the Trinidad asphalt, the uniformity of the proportions of bitumen to mineral matter is quite as striking. The bitumen is harder than that of the Trinidad and Bermudez deposits and is characterized by containing a considerable amount of sulphur derivatives of the asphaltic hydro-carbons.

Cuban asphalt is refined in the usual way by the application of heat until the material is sufficiently liquid to permit the settling out of the coarser mineral matter. Ordinarily a small amount of liquid asphalt is added to the crude material to assist in the refining operation and to facilitate sedimentation. After purification in this way the refined asphalt is drawn off into cubical moulds and allowed to cool. The refined asphalt is sufficiently inert to climatic temperatures so that the blocks which have been prepared in this way can be transported without any container. The advantage of this is obvious in that the purchaser derives the full benefit of net weights and the conveniences in handling the cubical blocks of standard weight.

For asphalt paving purposes, refined Cuban asphalt is fluxed

with a highly asphaltic base petroleum residuum. Particular care is taken in the selection of the fluxing materials to provide a fluxing agent capable of bringing out the valuable properties of the refined asphalt.

Cuban asphalt is a particularly valuable material in its adaptability to a wide range of uses. By variations in the character of the fluxing agents employed, various valuable properties may be developed to produce compounds relatively inert to temperature changes and possessing comparatively high melting-points such as may be required for roofing, filler, rubber substitutes, etc. For use as paving cement it is ordinarily combined with a highly asphaltic base Texas residuum. Paraffine residuums are never used with Cuban asphalt. The following special claims are made for this material:

"Cuban asphalt cement prepared in this way has given very successful results, particularly in those sections of the Middle West, where extremes of temperature and the sudden changes present trying conditions for successful asphalt paving work. Its ability to meet these conditions is probably due to the fact that it seems to combine the happy medium of those properties which are considered desirable by paving engineers. It is neither excessively ductile, nor is it by any means lacking in ductility, it is not affected by temperature changes as are the other commercial types of asphalt, yet it is not so inert that its adhesiveness and cementing abilities are in any way injured, as is the case with certain artificial products. Possibly its most striking characteristic is its ability to impart to the paving mixture a great degree of plasticity or malleability at low temperatures. It is this property which enables a street pavement to relieve itself of strains of construction without rupture or cracking. Cuban asphalt possesses this property to the greatest known degree, and probably on this account it has been so successful where trying conditions of temperature and traffic are met with."

Refined Cuban asphalt contains about 70 per cent of bitumen; the asphalt cement as used for paving purposes contains about 85 per cent of bitumen, the remainder being clay free from soluble salts, and is entirely unaffected by water. During recent years about 6,000,000 square yards of sheet asphalt, asphaltic concrete

and poured macadam pavements have been laid with this asphalt, and its use is steadily increasing in this country both in the paving industry and in other arts.

Barbadoes Asphalt.

A variety of bitumen known as "glance pitch" has been known for some time on the island of Barbadoes. It is a hard brittle asphalt, breaking with a clear brilliant fracture. It occurs in veins from an inch to a foot in thickness. It has never been used in, and is not suitable for, pavements, but its output is entirely consumed in the manufacture of varnishes, etc. It is almost wholly soluble in carbon bisulphide.

Asphalt in Turkey.

An important asphalt mine is located near Avalona on the Adriatic Sea. It belongs to the Sultan, but has been leased to a French syndicate. The material is taken out in both a solid and a liquid state and is exported to Europe and America. There are also other mines in the interior of Turkey in Asia belonging to the government and private parties, but they have not been worked to any extent on account of the bad transportation facilities.

Dead Sea Asphalt.

About the Dead Sea there is quite a quantity of asphalt belonging to the government. It is not used for any purpose, and persons found collecting it are fined or otherwise punished. It is said that in former times asphalt was frequently found floating on the surface of the Dead Sea, especially after earthquakes.

Syrian Asphalt.

There are four asphalt mines in Syria, but the one at Hasbaya is the most important. The mine has been worked at intervals by different lessees since 1864, but only 1000 tons per annum were taken out when actual operations were carried on. It is the private property of the Sultan, and has not been worked to any extent since 1893. From 1882 to 1892 about $70,000 worth of this material was exported to the United States, and in 1897 $3439 worth. In 1893 the product was worth about $90 per ton.

It is said that asphalt exists in this vicinity in large quantities, and under a favorable government thousands of tons might be mined each year.

A sample of the Hasbaya product is thus described: It is black with a bright jetlike lustre, making a blackish-brown streak on unsized paper. It is so brittle that pieces may easily be broken off with the fingers. It is very combustible, but a splinter held in the flames will melt before igniting. Its specific gravity is 1.104.

Egyptian Asphalt.

No natural asphalt is found in Egypt except in very small quantities above Suakim near Abyssinia, where it cannot be worked profitably, and some small deposits on the east coast of the Red Sea.

It is said, however, that two firms in Egypt manufacture artificial asphalt, importing material for their use from Italy, France, and England. What their process was, or to what uses their product was put, could not be learned.

CHAPTER IV.

BRICK-CLAYS AND THE MANUFACTURE OF PAVING-BRICK.

THE word clay as ordinarily used means any earthy substance which can be worked up with water into a plastic mass that when dried will retain any shape into which it may have been formed. Strictly speaking, the term applies to a single mineral, hydrated silicate of alumina, or kaolin. It is not, however, a natural mineral, but is the product of the decomposition of feldspar.

Beds of feldspar have often been found covered by the kaolin formed by the decomposition of a portion of its mass. This occurs when the feldspar is exposed to the action of water containing carbonic acid gas, which acts upon the alkaline base of the mineral and carries it away in solution, leaving the silicate of alumina behind. As, however, feldspar is seldom found in large quantities by itself, so deposits of pure kaolin are very rarely found. Commercially they are of considerable value.

When pure, kaolin is composed of:

	Per cent.
Silica	46.3
Alumina	39.8
Water	13.9

This is represented chemically by the formula $Al_2O_3 2SiO_2 2H_2O$. It is the base of all the substances known as clays, and as they are formed by the decomposition of rocks, so their chemical composition varies with that of the rocks from which they are derived.

Quartz and feldspar are the two minerals found in the greatest abundance in the earth's crust, and, very naturally, it is expected to find sand and clay as the most common of the products of the decomposition of rocks.

Feldspars are divided into three separate varieties: orthoclase, or potash feldspar; albite, or soda feldspar; and anorthite, or lime feldspar,—each of these varieties being minerals more or less complex. These, too, are at all times in the same mineral, which must be named by one of the terms used in the classification, the one in greatest abundance giving the character to the compound.

All feldspars are acted upon by the atmosphere. The oxygen, carbonic acid, and water contained in it, when taken together, form a solvent that is hard for rocks to resist, especially when supplemented by soil-waters containing more or less acids derived from decaying vegetable products.

Under these influences granites and other rocks containing feldspar, especially the potash variety, are rapidly decomposed. The feldspar having lost its cementing property, the rock falls into pieces. The carbonate of potash is dissolved in the water and borne away. The particles of quartz, mica, and other accessory minerals remain and become assimilated with silicate of alumina from the feldspar, all together making up the product commonly called clay. It can be readily seen that it cannot be a pure mineral and that its composition must vary greatly.

Kaolin has a specific gravity of from 1.5 to 2.2 and is white in color. It is soft to the touch when dry, and very plastic when wet. It has two marked chemical characteristics, insolubility and infusibility. It being the product of a soluble body, the former might be expected. It is not affected by ordinary chemical agents, nor by temperatures that have thus far been produced in the arts. It is consequently of greatest value in the manufacture of crucibles and other refractory utensils used in chemical research.

While this infusibility is true of kaolin, it is not true of clay. For the addition of different minerals found in nature often forms a compound that is easily fused. These minerals when thus used are called fluxes. Naming them in the order of their effectiveness, they are potash, soda, iron, lime, and magnesia. Very small amounts of one or more of these substances are required in any clay to destroy its value as a refractory material.

But on the other hand the finely divided silica of the original rock which is always found in a greater or less amount in most kaolin detracts not at all from its heat-resisting qualities, the silica

itself being practically infusible. For this reason free silica is practically the only impurity that is permissible in kaolin without detracting from its refractory material.

Feldspar and mica are found in nearly all clays, the latter often being discernible to the naked eye. The former, however, cannot be thus distinguished from free silica. These two minerals both contain alkalies in combination with silica and alumina, and so it is understood how alkalies can be discovered in clays by analysis, when it would not be expected to find them existing in a free state in a mineral whose origin was due to the action of water and other solvents.

The oxides and other compounds of iron are generally found in clays. The sesquioxide and the protoxide are the most common forms, but carbonates are not uncommon, and sulphides are occasional as well as injurious impurities. Iron gives the color to clays. The tints vary from buff to red, and from drab to blue or green, the amount of iron not seeming to determine the degree of color. The effect, too, of iron is very much heightened and changed by heat. The colors produced by burning vary from cream to perfectly black, with nearly all the intervening tints and shades, though the reds, browns, and greens are most common. A handsome cream-colored brick is made at Milwaukee, and others of pink color in certain parts of Canada.

Organic matter is frequently found in clays, but it is of little importance. It is generally caused by the presence of decomposing carbonaceous matter. It gives a color to the clay, but when subjected to even a comparatively low heat it is easily driven off. It is very seldom, therefore, that its presence is detrimental.

Clay can then be called a compound of a clay base with sand, feldspar, mica, and other silicates colored by iron oxides or organic matter.

The properties of clays by which their values are determined are: plasticity, so that when wet it is possible to shape it into any desirable form; the maintenance of this form, while it is being burnt, to such a degree that its shape is permanent; and its refractoriness, so that it is able to withstand great and long-continued heats without fusing.

Plasticity is a property that is shared by practically all clays.

As a rule they all tend towards crystallization, and some kaolins are made up of masses of unattached scales. These are slightly plastic and can be made more so by grinding and kneading in water, when an examination shows that the crystalline structure has been broken up. Naturally, plastic clays do not show this structure, indicating that a clay's plasticity depends upon the extent to which this structure has been destroyed.

In several places clays are found that are entirely free from plasticity, even after being ground and treated with water. Frost and the action of water disintegrate them and a fine sand is formed, but a chemical analysis shows them to be almost pure kaolin.

Permanence of form in clay ware is caused by heat. In ancient times and in dry climates bricks that were only dried in the sun have lasted for a considerable time, but they could not be called permanently shaped.

Generally speaking, if heat has been applied only sufficiently to drive out the water mechanically mixed, the mass will be porous, somewhat shrunken in form, and readily disintegrated under the action of the elements. If, however, the heat be increased and continued, the clay will shrink farther and harden, until, when the proper point is reached, a new material has been formed which is practically indestructible. If the heat be continued still further, the clay will become harder, more brittle, and often deformed. Other clays will melt and become glassy and lavalike, as is so often seen in arch-bricks of an old-fashioned wood-burning kiln.

Argillaceous matter as a whole is divided into two classes, clays and shales. Chemically they are often the same. Physically the shales can be detected by their stratified or laminated structure. They are hard and compact, and require considerable work to prepare them for use. Like the different kinds of granite, clays merge into shales and shales into clays, so that the line separating them must be an arbitrary one.

Shales must not be confounded with slates, which they very much resemble. Slates have been formed by the action of heat combined with great pressure. They are hard and durable rocks, while shales will rapidly disintegrate when exposed to the action of the atmosphere.

As a rule shales are formed in deeper water than clays. Their

laminations are supposed to have been caused by the intermittent deposit of the material of which they are formed, by pressure, or by both.

According to their composition, clays are divided into high- and low-grade clays. The first comprises clays and shales that contain in conjunction with not less than 50 per cent of kaolin base little else than finely divided silica. The other constituents rarely exceed 5 per cent and are often as low as 3 per cent. The second division includes all other clays and shales. They may run from 10 to 70 per cent of kaolin base; but always contain a large amount of fluxing material. The alkalies compose from 2 to 5 per cent, while lime, magnesia, and iron add two or three times as much more. As a rule the clays of the first division are refractory, and those of the second fusible.

Clays, however, are popularly classified into fire-clays, shales, and mud-clays. The first is a refractory clay of a high grade that cannot be fused at any temperature used in the arts. It is also subdivided into non-plastic and plastic varieties. The former are something of the nature of rocks, but upon exposure to the weather they crumble into fine particles similar to sand. With ordinary grinding they show no plasticity whatever, and would thus seem to want one of the main clay characteristics, but an analysis plainly shows their true character, while continued and repeated grinding develops plasticity.

Plastic fire-clays differ from mud-clays in the chemical composition, which gives them their refractory qualities. Kaolin or pure clay is, as has already been said, practically infusible, but it is seldom found in a pure state. The great mass of clays distributed over the earth's surface is impure, and upon the quantity and quality of the impurities depends the fusibility and refractoriness of the clay.

The principal impurity is quartz, which is not fusible at ordinary temperatures used in manufacturing, so that the fluxing elements of a clay are generally considered to be its impurities except quartz. Lime and magnesia are valuable as fluxes, except when they are present as carbonates in any considerable quantity, as they then lower the melting-point of the clay and a hard, tough brick cannot be produced by the burning. The condition of iron is also

important, free oxide being the least injurious. The more evenly it is scattered through the clay the better, so that vitrification may be as regular and even as possible.

Just how much of these fluxes can exist in a clay without destroying its refractory properties is uncertain. It depends greatly upon the character of the clay as well as upon the nature and number of the fluxes. Generally the finer-grained and less dense a clay is the more easily it is fused. The limit of the fluxes is probably from 5 to 7 per cent.

In the Report of the Geological Survey of Ohio analyses of fourteen different fire-clays used in the manufacture of paving-brick and sewer-pipe are given. The average of these showed 93.41 per cent of clay and sandy matter, with 5.65 per cent of iron and fluxes.

In commenting on this, it is said that this would indicate a clay more fusible than the stone- and yellow-ware clays, but far less fusible than the shales; also that the facts prove this, as the above clays, while vitrifying very well up to a thickness of two inches, are very difficult to vitrify when made into a brick or block.

The same authority gives the analyses of ten shales used for paving-brick and sewer-pipe. The average composition of these was:

	Per cent.
Clay and sand	84.78
Fluxes	13 22
	98.00

Enough has already been said to show the difference between fire-clays and shales. Their product also, when burned, is very different. The shales, containing so much more of the fluxing elements, can be more completely vitrified. A shale brick is harder, denser, and more brittle than one made of fire-clay. The latter absorbs more water, but is tougher. The advocates of both kinds claim all the virtues for their own product and allow very little to their rivals. It is certain, however, that good pavements have been laid with both varieties, and good results will be obtained if proper judgment be used in the selection, whichever kind is used.

In "Mineral Resources for 1897" the following tables are given

showing three stages of transformation of a German porphyry into kaolin, Table No. 11 giving the mechanical analysis and No. 12 the chemical composition of the rock at its corresponding change. No. 1 is the original porphyry, No. 2 an intermediate stage, and No. 3 the resulting kaolin.

TABLE No. 11.

	No. 1.	No. 2.	No. 3.
Coarse sand	33.95	22.56	2.48
Fine sand	36.20	37.40	28.52
Finest sand	7.90	12.15	18.42
Clay	9.27	12.26	20.51
Fine clay	7.46	8.55	17.69
Finest floating particles	5.22	7.08	12.38
	100.00	100.00	100.00

TABLE No. 12.

	No. 1.	No. 2.	No. 3.
SiO_2	77.48	75.73	76.48
Al_2O_3	17.10	21.92	21.58
Fe_2O_3	2.83	.98	.97
MnO	.84	.18	.17
CaO	.38	.27	.25
MgO	.10	.10	.07
K_2O	1.03	.55	.16
Na_2O	.13	.08	.01
P_2O	Trace	....	....
	99.89	99.81	99.69

The word "vitrification" is defined in the Century Dictionary as "conversion into glass, or in general into a material having a glassy or vitreous structure"; and "vitreous" as "resembling glass, glassy"; but these same words as applied to brick or sewer-pipe have come to receive a very different meaning. A glassy brick would not make a good pavement. It would be smooth and brittle.

As applied to brick the term vitrified means that a chemical action has taken place so that the clay particles have coalesced and become fused by the action of heat, forming a solid new homogeneous whole, but not that the fusion has been made complete and the entire mass brought to a semi-liquid condition. In some clays the

character of the material is such that the proper chemical union for vitrification will not take place, so that the brick absorbs water no matter to what heat it may have been subjected, and accordingly will not vitrify in this sense of the word. Many engineers, therefore, have decided upon the absorption test as the proper one to determine to what degree a brick has become vitrified. A thoroughly vitrified brick breaks with a smooth conchoidal fracture and has no visible pores. The burned particles and granulated structure so plainly discerned in a half-burned building-brick have all disappeared.

A clay from which such brick can be successfully and profitably made must be both fusible and refractory. Unless it be fusible the product will not vitrify at all, and yet if it have this property in too great a degree, the clay will melt and lose its shape upon the application of great heat. It should be sufficiently refractory to allow the vitrifying heat to be applied within considerable limits, so that if the temperature be increased a hundred degrees or more after vitrification has set in, the form of the brick will not be injured. The more equally refractoriness and fusibility can be opposed to each other, with neither property being pushed to extremes by the heat used by the average burner, the greater will be the percentage of the finished product of the kiln.

The proper amount of plasticity must also be obtained. If it be too small, the clay particles will not assimilate in the new state, so that when burned the material will be porous and have little cohesive strength. If, on the other hand, it be too plastic, the mud will retain its shape and position to such an extent after being machined that the twist given the clay, especially if an auger machine be used, is often plainly visible in the finished product and laminations are formed with appreciable voids between the different layers, thus reducing the strength of the brick. These, however, are mechanical faults and can be easily corrected by a study of the crude material and the application of the proper remedy. Shales as a rule are less plastic than clays and require grinding before they can be used, and in many cases a mixture of a certain percentage of clay to bring about the proper degree of plasticity.

By the proper mixing of clays possessing different degrees of fusibility and refractoriness a combination is often reached that

permits the utilization of a great number of clays that would otherwise be valueless for vitrified products. Perfectly satisfactory clays are not often found in a natural state.

Burned or dried clay has been in use as pottery or bricks for many centuries. Pottery has been made by all prehistoric races, with the single exception of the cave-dwellers of the Drift period, from the Neolithic. The early specimens were rudely shaped and made by hand, but appliances for forming the clay were gradually discovered, and the Egyptians were known to have used potter's wheels as early as 4000 B.C.

Allusion is also made to the wheel in Jeremiah xviii. 3, 4, as well as in several places in Homer. Fragments of pottery have been found in clay-brick used in the construction of the oldest pyramid.

Bricks themselves were used in the tower of Babel, as well as in the walls of the city of Babylon. The children of Israel made bricks of clay and chopped straw during their captivity in Egypt under Pharaoh. These were probably baked in the sun, although about that time some bricks were burned by the Egyptians.

Samples of enamelled work were found on the walls of the palace of Rameses II. built about 140 B.C. Bricks were also extensively used in the palaces of Babylon and Nineveh constructed some two hundred years later.

Some of the pyramids were made of bricks, and upon one of them was found this inscription:

"Do not undervalue me by comparing me with pyramids of stone. For I am better than they, as Jove exceeds the other deities. I am made of bricks, from clay brought up from the bottom of the lake adhering to poles." This shows that even at that period bricks had been used for a sufficient time to demonstrate their enduring qualities.

They were used to a great extent by the ancient Greeks and Romans, the former being said to have brought them to perfection.

The walls and temples of Athens, as well as the palace of Crœsus, were constructed wholly or in part of brick, though, on account of stone being so plentiful in Greece, they were not in so great a demand there as in other countries.

Strabo mentions a floating brick made of a kind of silicious earth that when burned has a less specific gravity than water.

Modern bricks were first used in Suffolk, England, in 1260, though they were not manufactured of good quality until about one hundred years later. They did not come into general use in London till after the great fire in 1660.

The first brick-kiln in this country was probably built in Salem, Mass., in 1629, although for some years after the early settlements nearly all of the bricks used here were brought from Holland or England. In old houses in Albany, N. Y., and vicinity some of the original Dutch bricks can still be found.

The manufacture of paving-bricks is of comparatively recent origin. They were first used in this country as paving material in 1870. And not for some time after that did brick-makers realize that a new industry had been opened up for them. But in 1807 it had been developed to such an extent that in that year there were manufactured in the United States 435,851,000 vitrified bricks, having a value of $3,582,037. Illinois headed the list of States with 87,169,000, closely followed by Ohio with 85,-665,000.

In 1898 the production was 462,499,000, valued at $3,922,642, but Ohio had displaced Illinois for first place with a total of 115,-104,000, against 71,999,000 for the latter State, the average price per thousand being $6.92 in Ohio and $8.88 in Illinois.

In 1910 the quantity manufactured had increased to 968,000,000, valued at $11,004,666, Ohio still leading the states with a production of 289,817,000, valued at $2,876,157, as against Illinois with 115,903,000, valued at $1,415,355, the value being $9.92 per thousand in Ohio and $12.21 in Illinois.

A peculiar "blue brick," so called, is made for paving purposes in Birmingham, England. The material used is a very ferruginous shale. After the bricks have been placed in a kiln the heat is raised to the vitrification-point. Salt is then thrown on the fire and, being volatilized by the heat, covers the bricks with a thin glaze. Fresh coal is also added to the fire at the same time, and all openings in the kiln tightly closed. This causes a reduction in the iron near the surface of the bricks and a thorough fusing of the particles in this outer crust. The process makes a hard, dense

brick with the outer inch or half-inch a bluish black, while the innet portion is a deep red.

The Manufacture of Paving-brick.

Vitrified paving-brick have been in use in this country a little more than 35 years, as a wearing surface for streets and highways. In their early history little attention was given to using them in the most advantageous way, either as to durability or as to the possible satisfaction in their use. It was rather a combination of varied ideas of construction using a good material with no definite realization of what is really possible in a brick street constructed under the most approved methods of to-day. As the use of brick has been extended, its merits have grown in favor and the possibilities appreciated, until vitrified brick are universally recognized as a necessary factor in civilization.

The service required of a paving-brick has made it necessary for the manufacturers to produce an artificial rock of given dimension which shall have both the qualities of hardness and toughness. These two qualities in the brick make it possible with proper construction, to produce a pavement surface which will successfully resist both the abrasion and shock of traffic and wear and tear of time and weather.

Vitrified paving brick are manufactured from the less refractory fire clays and shales which are found in almost all of the bituminous bearing deposits throughout the United States. No two deposits of these shales or clays are exactly alike: they do not burn alike either in color or in the amount of heat required to bring them into the best condition adaptable for their use, so that the raw material must receive slightly different treatment at each of the factories. On this account, brick of different manufacture differ in appearance.

Occasionally, the character of the shale or clay used makes it desirable to add a percentage of sand or surface clay. No certain chemical analysis of clay can be said to produce the best paving brick for the reason that the quality of the brick resulting from the firing of the clay is dependent as much upon the physical arrangement and condition of the various minerals it contains, as upon their chemical constituency. Therefore,

as the various strata of shale contain different proportions of different minerals in the bank or natural deposit, it sometimes becomes necessary to carefully mix these strata to produce the best results. In other deposits this mixture may have already been made by natural processes.

A brick burned sufficiently to develop the best quality from any one of the clays and shales used, is almost impervious; at least sufficiently so that the amount of moisture absorbed regardless of temperature, does not affect the brick in any way. The adhesion of the particles is brought about by sufficient heat to bring them into a molten state. The process has brought into a new use the word "vitrified," and in connection with the manufacture of paving brick that word is given a new meaning. It does not mean that a perfect vitrification is obtained as in the manufacture of glass, but an approach to it, forming a coalescent body. The manufactured product is therefore both tough and strong, most perfectly adapted for resisting the wear and tear to which road surfaces are subjected.

Shales are of common occurrence, often in such quantity and position as to enable them to be dug most economically by means of steam shovel or other mechanical device. In some cases, however, the deposits are comparatively thin and underlie objectionable rock or earth and therefore have to be mined at a much higher cost. Fire clays usually occur with coal deposits which may or may not be workable. These clays are therefore usually mined. The general distinction between fire clays and shales is that the latter contains iron in some form, which produces a red-burning clay, while the absence of iron in the former makes it a white-burning clay. Some low-grade fire clays however, may be blackened by certain firing conditions, too complicated to discuss in detail.

The general preparation of the clays is identical with either material. The material is brought by some convenient means to a grinding machine known in the art as a dry pan, after having been crushed or broken into comparatively small fragments. Beiefly this machine consists of a solid plate of iron some 5 feet in diameter, surrounded by a perforated iron surface about 2 feet wide. Outside the perforated surface is a rim, 14 or 16 inches

high to prevent escape of clay except through the perforations. On the solid plate rests two massive crushers or molars, each weighing $2\frac{1}{2}$ to 3 tons. The bottom is revolved rapidly by friction, crushing the clay as they turn, which is thrown by centrifugal force upon the perforated plates through which it falls into an elevator and is carried to the screens.

The mesh of screen varies in different factories from $\frac{1}{16}$ to $\frac{3}{16}$ inch. The particles which are too large are returned to the pan and those which are sufficiently fine are passed by means of conveyors to a mixing machine or pug mill. In the pug mill the ground clay is mixed with water to a stiff mud and fed continuously into the brick machine proper. The machine is extremely heavy and by an arrangement of screw propellers or augers on a revolving shaft the clay is forced into a tapering barrel, one end of which terminates in the die or former.

The clay issues from the die under heavy pressure in a solid column. If this column is approximately $4\frac{1}{2}$ by 10 inches it is cut automatically into sections $3\frac{1}{2}$ inches long and the resulting brick is "side cut." If the column is approximately 4 by $4\frac{1}{2}$ inches, it is cut into sections 10 inches long and the brick are then "end cut." Both end-cut and side-cut brick are then repressed for the purpose of smoothing and rounding the corners and edges and stamping upon the brick some trade mark. Lugs to separate the brick so as provide a uniform space for cement filler when laid in the pavement, are also produced by repressing or, if the brick is not repressed, the lugs may be produced upon the side of the brick when the column is cut into sections.

Special shapes, such as nose brick for use next to street-railway tracks, and hillside block, which have one side thicker than the other so as to give the pavement a rough surface, are made either by special die or special repress moulds.

As the brick leave the presses they are placed upon dryer cars in such a way as to permit a free circulation of air between them, and the loaded car run into a tunnel dryer, the temperature of which is maintained at about 100° F., where they enter. The tunnels are over 100 feet long and as the green bricks are put in at one end, dry ones are taken out at the other where the temperature is much higher. Circulation of air is either attained

by means of a section fan or blowers or high stacks. The amount of moisture taken out in the drying amounts to 15 to 20 per cent of the weight of the brick.

The dried brick are ready for burning and upon that step in the manufacture depends largely the quality of the finished product. The burning is done in kilns constructed of brick and arranged with furnaces by means of which a high temperature may be produced in the kiln. The brick are set in the kiln so as to allow a free circulation of heated air and the products of combustion.

Kilns are of different construction, the following diagram giving an idea of the variation. Good paving block may be and are produced in each of the different types of kiln.

Semi-continuous	Tunnel	Gas-fired	
		Direct-fired	
	Chambered	Gas-fired	
		Direct-fired	
Periodic	Updraft		
	Downdraft	Rectangular	Multiple stack
		Round	Single stack
			Multiple stack

The temperatures required vary with the material from 1800° to 2400° F., for shales and higher for fire clays.

Brick shrink both in drying and burning, the total amounting to from 8 to 12 per cent. For that reason the narrow kiln is considered best for burning paving block, as there is less danger of distorting the brick. Also burning time varies from 150 to 336 hours. Cooling requires from 1 to 2 weeks.

Only block which will pass certain requirements, about 80 per cent of the output, can be shipped for street work. The remainder are sold for private work or masonry perposes. For first-class paving the block must be well burned, free from excessive kiln marks and present at least one fairly straight face. They must also resist abrasion and shock, and to determine the latter qualities, most plants test brick from each kiln, using the National Paving Brick Manufacturers' Association Test, which has been adopted by the American Society of Municipal Improvements and The Association for Standardizing Paving Specifications.

The study of this Rattler test for paving brick has been laid before the American Society for Testing Materials, by the authors, Messrs. Blair and Orton.

Possible and further refinement of this method of testing may be developed by further research work on the part of these gentlemen.

CHAPTER V.

CEMENT, CEMENT MORTAR, AND CONCRETE.

When a pure limestone has been properly burned or calcined the result is lime, that is, the carbonic acid has been driven off by the action of the heat. When water is applied to the lime it slakes with a great increase in volume, and if more be added it can be formed into a paste, which when mixed with sand will harden or set if exposed to the air.

Limestone, however, is very seldom found in a pure state, the principal impurities generally being silica, alumina, iron, and magnesia. When these impurities exceed 10 per cent the resulting lime has the property of setting under water and is said to be "hydraulic." If, however, the rock contains about 40 per cent of silica and alumina, the product of the calcination will not slake upon the application of water, but must be reduced to a powder in mills, when it is made into a paste as with the lime. This product is known as "cement." It differs from lime physically in that it requires to be reduced to a powder before being used, and does not materially increase its volume in setting.

Cements were known to and largely used by the Romans, and it is said that the workmen excavating in London, England, in 1892 found a natural-cement concrete which was known to have been laid eight hundred years before. During the middle ages there seems to have been little knowledge of limes and cements, as what is known at present dates back to the time when John Smeaton, in seeking for a mortar with which to construct the Eddystone lighthouse, discovered the hydraulic character of certain limestones, and that this property was caused by the presence of clay in the original rock.

Cements are generally spoken of in this country as "natural"

or "artificial." The former, as the name implies, is made from the natural rock, while the latter is an artificial mixture, the ingredients being so proportioned as to bring about the best results. As might be expected, the latter are stronger, more durable, and much more expensive. Artificial cements are also known as "Portlands" from the fact that they were first manufactured in England, and that when set they bore a strong resemblance to the natural stone found in the island of Portland. In a very few localities limestone has been found which when burned has almost the same composition as the artificial Portlands. On account of this similarity these have been called "natural Portlands." A cement of this character was produced in France in 1802. Portland cement as known at the present time was first manufactured in England in about 1824, although patents for "Portland cements" had been issued several years previously.

The following is the description given by the patentee in the first specifications issued:

"I take a specific quantity of limestone and calcine it. I then take a specific quantity of clay and mix it with water to a state approaching impalpability. After this proceeding I put the above mixture into a slip-pan for evaporation till the water is entirely evaporated. Then I break the said mixture into suitable lumps and calcine them in a furnace similar to a lime-kiln until the carbonic acid is entirely expelled. The mixture so calcined is to be ground to a fine powder, and it is then in a fit state for cementing. The powder is to be mixed with a sufficient quantity of water to bring it into the consistency of mortar, and this applied to the purposes wanted."

In 1796 a Mr. Parker of London patented a process of making a "Roman" cement. This was so called, and properly, on account of the similarity to the cement in use by the Romans so many years before.

In this country a cement similar to the above was manufactured at Fayetteville, N. Y., in 1818.

Portland cement was first produced in the United States in 1865. At the present time cement works are situated in twenty-six states; Pennsylvania, Indiana, and Kansas producing in 1910 more then one-half of the total production.

In 1828 a natural-cement rock was discovered at Rosendale, New York, and afterwards similar formations in other portions which, on account of the similarity, were also called "Rosendales," being distinguishable from each other by a special name for each brand. As the country was settled and construction work was undertaken in other sections, more deposits were found, a notable one near Louisville, Ky., and now some authorities call all natural cements "Rosendales," to separate them from the "Portlands."

In the Building Code now in use by the city of New York the following is found in relation to Portland and other cements:

"Cements classed as Portland shall be considered to mean such cement as will, when tested neat, after one day set in air be capable of sustaining without rupture a tensile strain of at least 120 pounds per square inch, and after one day in air and six days in water be capable of sustaining without rupture a tensile strain of at least 300 pounds per square inch. Cements other than Portland cement shall be considered to mean such cement as will, when tested neat, after one day set in air be capable of sustaining without rupture a tensile strain of at least 60 pounds per square inch, and after one day in air and six days in water be capable of sustaining without rupture a tensile strain of at least 120 pounds per square inch. Said tests are to be made under the supervision of the Commissioner of Buildings having jurisdiction, at such times as he may determine, and a record of all cements answering the above requirements shall be kept for public information."

It will be seen by the above that the cement is graded by its strength. This standard is, perhaps, as satisfactory as any, if the tests are carried on for a sufficient length of time, but most engineers would hesitate to accept or reject cements of which they knew nothing, from the result of so short a time-test as seven days. Under this clause no cements can be used that develop a strength of less than 60 pounds in one day set in air.

The American Society for Testing Materials defines natural and Portland cements as follows:

Natural Cement.

"This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone

at a temperature only sufficient to drive off the carbonic acid gas."

PORTLAND CEMENT.

" This term is applied to the finely pulverized product resulting from the calcination and incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials and to which no addition greater than three (3) per cent has been made subject to calcination."

Natural and Portland cements can be readily distinguished, however, by their composition.

Table No. 13 is made up from analyses of well-known cements and taken from Cumming's " American Cements."

TABLE No. 13.

PORTLAND CEMENTS.

Brand.	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Potash and Soda.	Sulphate of Lime.	Carbonic Acid, Water, and Undetermined.
K. B. & S.	19.75	7.48	5.01	60.71	1.28	0.75	1.64	3.38
Alsen	24.90	8.00	3.22	59.38	0.38	0.50	1.46	2.16
Dyckerhoff	19.35	7.00	4.50	63.75	......	......	......	5.40
Germania	21.14	6.30	2.50	66.04	1.11	......	......	2.91
Saylor	22.91	8.00	1.90	61.76	2.70	......	......	2.63
Giant	23.36	8.07	4.83	58.93	1.00	0.50	0.85	2.46
Alpha	22.89	8.00	2.44	63.38	2.30	......	......	0.99
Natural, Boulogne, France	20.42	12.00	1.87	63.13	0.58	......	......	2.00
Average	21.84	8.11	3.28	62.12	1.17	......	......	2.74

Mr. Launcelot Andrews, Ph.D., in an article on cements in *Clay Record* says that an ideal Portland cement should be composed of:

	Per cent.
Lime	62.2
Silica	28.2
Alumina	9.6

but adds that about a third of the alumina may be replaced by ferric oxide, which would correspond to the composition:

	Per cent.
Lime	61.7
Silica	27.4
Alumina	7.5
Ferric oxide	3.4

He also gives 3 per cent of magnesia as the maximum to be allowed, a larger amount having a tendency to cause the cement to swell and crumble.

Table No. 14 shows the composition of several well-known American cements, also taken from Cumming's "American Cements."

TABLE NO. 14.

NATURAL CEMENTS.

Brand.	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Potash and Soda.	Carbonic Acid, Water, and Undetermined
Utica	34.66	5.10	1.00	30.24	18.00	6.16	4.84
Milwaukee	23.16	6.33	1.71	36.08	20.38	5.27	7.07
Louisville, "Four Leaf"	26.40	6.28	1.00	45.22	9.00	4.24	7.86
Louisville, "Hulme Star"	25.28	7.85	1.43	44.65	9.50	4.25	7.04
Hoffman	27.30	7.14	1.80	35.98	18.00	6.80	2.98
Norton, High Falls	27.98	7.28	1.70	37.59	15.00	7.96	2.49
Mankato	28.43	6.71	1.94	36.31	23.89	1.80	0.92
Average	27.60	6.67	1.51	38.01	16.25	5.21	4.74

It will be noticed that the two brands of Louisville very quick-setting cements are high in lime and correspondingly low in magnesia, that there is a difference between the naturals and Portlands in every essential ingredient, and that it is so marked that the one can always be distinguished from the other.

Fineness.

Besides its composition, there is another property of cement which has an important bearing upon its value in mortar, and that is its fineness. It costs materially more to grind a cement so that 75 per cent of it will pass a sieve of 40,000 meshes per square inch than to pass one of 10,000, so that the tendency is to leave the product as coarse as possible and get satisfactory results. Gillmore says: "The capacity of a cement to receive sand, other things being equal, varies directly with its degree of fineness." As cements are always used in practice mixed with a certain amount of sand, this matter is of great importance. The author just quoted says that not more than 8 per cent of a cement should be rejected by a sieve of 6400 meshes to the square inch. Mr. Andrews, previously referred to, says that all grains so large as not to pass a sieve of 75 meshes to the linear inch (5625 per square inch) should be considered as inert or wholly passive constituents, and that they should not constitute more than 20 per cent of the total weight.

Mr. R. W. Lesley in examining different specifications upon this point found the requirements as shown in Table No. 15 (the results being given in a paper read before the Engineers' Club of Philadelphia).

TABLE No. 15.

PORTLAND CEMENTS.

Brand.	Percentages to pass Screens of the following Meshes per Square Inch.					
	2500	3600	6400	8000	10000	40000
U. S. Army	95½	......	......	......	84	70
Lighthouse Board	95	......	......	......	......	......
U. S. Navy	......	97	90	......	......	......
District of Columbia	95	......	......	......	85	......
Nine cities	97	......	......	......	89	69
Six street and steam railways	95½	......	......	80	......	......
A number of bridge companies	97	......	......	......	......	......
Average of 71 specifications	96	.....	......	......	85	69
AMERICAN CEMENTS.						
Average of 38 American specifications	92	......	85	......	79	......
U. S. Army	91	......	85	......	72½	......

TABLE NO. 16.

Brand.	Age of Specimen.	Percentage retained on a No. 120 Sieve.	Parts of Sand to one part of Cement.				
			0	2	3	4	5
English Portland....	7 days	37	319	125	89	59	43
French Portland. ...	do.	13	318	205	180	114	86

TABLE NO. 17.

Brand.	Age of Specimen.	Percentage retained on a No. 120 Sieve.	Parts of Sand to one part of Cement.		
			0	3	5
Ordinary Portland	28 days	35	408	105	68
Finely ground Portland	28 days	12	304	180	96

TABLE NO. 18.

Brand.	Age of Specimen.	Percentage retained on a No. 50 Sieve.	Parts of Sand to one part of Cement.		
			0	1½	3
Coarse Rosendale......	7 days	17	98	29	16
Fine Rosendale........	7 days	6	92	41	25

In prosecuting the Boston Main Drainage Works, Mr. Eliot C. Clarke made some very elaborate experiments to show the effect of fine grinding on cements. In Tables Nos. 16 and 17 are given some of his results. The figures represent the tensile strength in pounds per square inch.

In Table No. 17 the same brand was used in both cases, but one sample was taken from the ordinary delivery, and the other from a lot that had been ground in accordance with a special contract.

Another test was made by taking the average of these brands of finely ground with the same number more coarsely ground, with the results shown in Table No. 18.

These tables show conclusively the value of fine grinding, and, as far as investigations have been carried, that the finer the cement is ground the more strength it will have when mixed with sand. On account of the great cost of extreme grinding, it is not economical to carry it too far. From the figures previously given, it would seem that the authorities had decided upon a sieve of 200 meshes to the linear inch as the limit to be required.

In the final report on Tests of Cement by the Committee of the American Society of Civil Engineers it is said on this point: "It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses cementing qualities. The more finely cement is pulverized, other conditions being the same, the more sand it will carry and produce a mortar of a given strength."

Concerning the tests to be made of cements to determine its real value or its special fitness for any particular work, there is much to be said. Different engineers have different requirements when seeking for the same results, and different laboratories differ very much among themselves in their methods, and consequently their results vary materially even when cement from the same barrel is used. The best illustration of this is shown in Table No. 19, taken from a paper by Prof. J. M. Porter of Lafayette College. Prof. Porter had ten samples taken from the same number of barrels of Portland cement, thoroughly mixed, and then divided into ten smaller portions which were sent to ten different persons with a request that a seven-day tensile test, one cement to three sand, be made according to the standard of the American Society of Civil Engineers.

These results would seem to indicate that such tests are of little value when a report from one laboratory would cause the cement to be rejected without hesitation under ordinary specifications, and as unhesitatingly accepted according to the report of another equally reliable, and when a special effort has been made to have all conditions as nearly alike as possible. This is hard to explain. But on account of these variations tests of cement must not be given up, but continued with more care, and perhaps on different lines.

It is rarely possible to give the cement used in any large and

TABLE No. 19.

	Tensile Strength in Pounds.							Range in Pounds.	Ratio of Range to Maximum.	Ratio of Average to Last.	Water, per ct.
	1	2	3	4	5	6	Average.				
R. W. Hildreth & Co., New York..	68	72	74	78	82	....	75	14	17.1	30.4	12
Prof. J. B. Johnson, Washington University, St. Louis....	77	94	108	110	122	...	102	45	36.9	41.8	Not given
H. R. Fahr, City Engineer, Easton, Pa....	106	112	123	...	....	....	114	17	13.8	46.5	10.4
Prof. W. H. Burr, Columbia College, New York...	125	126	130	137	140	144	133	19	13.2	54.0	10
	126	132	138	144	150	153	140	27	17.7	56.8	8
Chas. F. McKenna, New York	148	150	151	155	160	....	153	12	7.5	62.0	12
Prof. F. P. Spalding, Cornell University, Ithaca	155	160	164	166	172	....	163	17	9.9	66.0	Not given
Prof. J. N. Porter, Lafayette College, Easton	171	177	177	178	179	....	176	8	4.5	71.4	11
Clifford Richardson, Washington.	220	224	226	228	228	.	225	8	3.5	91.2	10
Booth Garrett & Blair, Phila......	240	246	249	250	252	....	247	12	4.8	100	12
Average.............	...	...	....	..	..	...	153	17.9	12.9	62.0	10.8

important work sufficient tests to demonstrate its absolute fitness. It must be done analogically. It is necessary, however, to find a brand of cement before the work is begun that either by experience or long-time tests has been proved to be all that is required. If the former, a series of tests should be made extending over a sufficient period of time and comprising enough individual samples of the cement to establish a rigid standard for that particular brand. It should include neat tests and also those mixed with every proportion of sand that is liable to be used on the work, to ascertain as well what mixture of sand will produce the requisite strength. During construction work cement is liable to be delivered in such quantities that it is not possible to make long-time tests without working a hardship on the contractor. If, however, a standard has been established, and it is definitely known that a certain strength neat in seven days will develop into a certain other strength in thirty or ninety days mixed with the specified amount of sand, a very accurate and satisfactory conclusion can be arrived at. Each cement, however, must have its own standard, and the operator who makes the original tests should be retained to carry them on during the prosecution of the work.

No new cement should be accepted on short-time tests. They are often very deceptive. Unless it has been used and gained a reputation, careful and elaborate tests should be made as detailed

above. The briquettes should be mixed neat and with the proportions of sand determined upon, the same day and by the same person, using the same sample of cement for both neat and sand briquettes, so that the loss of strength occasioned by the added sand can be accurately determined. Long-time tests are absolutely necessary, as a few cements with a moderate amount of sand will give practically as great a strength as when tested neat. As it is long-time results that are desired in construction, the importance of this can be readily seen. Table No. 20 clearly illustrates this.

TABLE NO. 20.

Age of Specimen.	Neat.	One Part Cement, Two Parts Sand.
24 hours	40	...
7 days	107	46
28 days	254	162
2 months	346	245
3 months	388	311
6 months	450	436

The above is the average of five briquettes, and the cement is a natural product well known in the New York market. Thirty per cent of water was used in the neat mixture and 14 per cent in the sand.

Mr. E. B. Noyes, in *Journal of Engineering Societies* for June 1896, gives a case in point when a good cement was rejected and a poorer one accepted on comparatively short-time tests without apparently any previous knowledge. Table No. 21 gives his results.

TABLE NO. 21.

	7 Days.	28 Days.	6 Months.	12 Months.
1	19	41	210	518
2	12	24	136	530
3	42	115	202	334
4	71	182	283	260

The cement was a natural brand, and the briquettes were mixed one part cement to one part of sand. Nos. 1 and 2 were not used on account of their poor showing in their first tests, while at the end of the year their superiority was clearly demonstrated. No. 2 was certainly a remarkable specimen, and any engineer would be justified in rejecting it upon the six months' test without having had any previous knowledge of its wonderful recuperative powers. In many works, too, it could not be used notwithstanding its great strength in one year, as its development during the first six months is very slow. Sample No. 4 actually receded in strength, though so little that it might have been caused by some individual briquette. It would seem to be a fair inference that it had practically reached its limit in six months.

The author several years ago had some tests made of the principal natural cements tributary to the city where he was then located, practically on the lines as indicated above. The results were very satisfactory, demonstrating the necessity of such action, and in this particular case bearing out some action that had been taken in rejecting certain cements. Table No. 22 gives the results attained.

TABLE No. 22.

CEMENT MIXED NEAT.

Briquettes 1 day in air, remainder in water.

	24 Hours.	7 Days.	15 Days.	30 Days.	90 Days.	6 Months.	9 Months.	1 Year.
1	109	112	145	155	250	241	289	227
2	214	228	219	325	387	366	421	316
3	114	186	223	290	282	291	347	339
4	87	197	237	264	267	220	367	288
5	46	131	199	279	298	322	402	410
6	206	248	348	348	334	355	372	402
CEMENT 1 PART, SAND 2 PARTS, REMAINDER IN WATER.								
Briquettes 1 day in air.								
1	....	35	80	167	216	199	197	229
2	....	40	79	122	148	155	112	161
3	....	38	76	114	75	89	89	82
4	....	74	99	134	140	146	153	137
5	....	26	53	95	141	153	145	142
6	....	81	103	138	106	81	69	84

This shows that No. 1, which was the weakest at the end of a year neat, was the strongest when mixed as it is generally used; and that Nos. 3 and 6, which were two of the highest neat, were but one-half the average strength of the others at the end of the year when mixed with sand.

Some engineers in making cement specifications go very elaborately into the component parts of the material, exacting a certain percentage of one substance and ruling out more than a certain amount of another. This practice is dangerous, unless one is perfectly sure of his standing, or the limits are so elastic as to be of no value. It is really encroaching on the prerogative of the manufacturer. The engineer wishes results, and it is the maker's business to produce a cement that will give them. The manufacturer will have no difficulty in meeting any requirements, but at what cost to the long-time test he alone might be able to tell. Then the products of different mills differ so that a slight excess of one ingredient might be neutralized by that of another. It is well known that many excellent brands of cement are made. It is better to obtain a perfect knowledge of the peculiarities of each and, after specifying certain of these, make sure that each delivery is kept up to the standard.

In the case of an excessive demand when the output is small, manufacturers are liable to put on the market a product that in the rush has not received sufficient attention, and which ordinarily would not be sent forth—or it may happen without their knowledge. It is the object of the tests to detect this or similar defects in standard brands.

In the paper by Mr. Lesley previously referred to, he gives the requirements for tensile strength as found in different specifications and shown in Table No. 23.

Cement specifications generally specify a time within certain limits for the initial and final sets. When this is done, and in fact the time of setting is generally noted in all tests, it is necessary to define what is meant by these terms. A standard was first adopted by General Totten at his work at Fort Adams, R. I., previous to 1830. This was that when the mortar would sustain a wire of $^1/_{12}$ inch diameter weighted to $^1/_4$ pound, it should be said to have received its initial set, and its final when it would sustain a

TABLE No. 23.

PORTLAND CEMENTS.

	24 Hours Neat.	7 Days.		28 Days.	
		Neat.	1 to 3.	Neat.	1 to 3.
U. S. Army	131	402	119	547	189
Lighthouse Board	....	383	85	600	....
U. S. Navy	....	462	....	....	....
City specifications	161	388	134	538	201
Railroads	115	319	....	483	....
Average of a number of specifications	134	384	118	529	189

NATURAL CEMENTS.

	24 Hours Neat.	7 Days.		28 Days.	
		Neat.	1 to 2.	Neat.	1 to 2.
U. S. Army	40–70	90–125	25–50	100–200	65–200
City specifications	50–100	100–200	....	150–300	....

wire of $^1/_{12}$ inch diameter bearing a 1-pound weight. The actual setting-point must be obtained by frequent trials. This standard was accepted by Gillmore and others.

The detailed specifications for cement and the methods of testing will be found in the chapter on Concrete Pavements.

Just what requirements should be called for in special cases depend upon the conditions under which it is to be used. It can be readily understood that it is not good engineering to insist upon a cement conforming to certain standards in all cases when at one time, for instance, it may be used as a foundation for a street pavement in dry work, and at another be laid in running water. In one instance a quick-setting cement is absolutely necessary, and in the other one that is moderately slow in taking its initial set

is better. What should be done is to ascertain what the requirements of the work are and then use a cement that, as it is generally manufactured, comes the nearest to meeting these requirements. Tests should be continually made to ascertain if it is being kept up to its standard. One principle should be strictly adhered to in making tests of any kind of material: *have the conditions governing the tests conform as closely as may be to those under which the material is to be used.* Eliminate as much theory and uncertainty as possible, and spend neither time nor money in attaining a requirement that will never be of any benefit to the work.

In actual construction cement is almost never used neat. It is first mixed with sand and water, and then is called mortar. Twenty years ago there was more natural cement used than Portland, but with the increase in the manufacture of the latter, and its consequent decrease in price, the consumption of natural cement has become very small, and Portland cement is used in practically all works of any magnitude.

The proportion of cement in sand is important as determining the strength of the mortar, and the character of the work must determine the proportion to be used. In cement concrete for pavement foundations the proportion is generally one of cement to three of sand, but if extraordinary strength is required it can easily be obtained by reducing the amount of sand; or in some cases the amount of sand may be made even four parts.

As it is the mortar that is to be used, whether in regular masonry or concrete, it is important and necessary to know the resulting volume from mixing of cement and sand in different proportions.

It should be specified, also, whether the cement is to be measured as originally packed or as poured loosely into the measuring-box.

Tables Nos. 24 and 25 give the results of experiments made by L. C. Sabin, U. S. Assistant Engineer, to ascertain the amount of sand and cement required to make a cubic yard of mortar under different conditions.

TABLE No. 24.

Parts of Sand to one of Cement.	Barrels Cement. 265 lbs. 71 lbs. per cu. ft. Cement packed 3.73 cu. ft. per bbl.	Cubic Yards Loose Sand.	Barrels Cement. 280 lbs. 75 lbs. per cu. ft. Cement packed 3.73 cu. ft. per bbl.	Cubic Yards Loose Sand.	Barrels Cement. 300 lbs. per bbl. 80 lbs. per cu. ft. Cement packed 3.75 cu ft. per bbl.	All Sand weighed 100 lbs. per cu. ft., voids 37½ per cent. Cubic Yards Loose Sand.
1	4.45	0.61	4.32	0.60	4.17	0.58
2	2.88	0.78	2.79	0.77	2.75	0.76
3	2.04	0.85	2.03	0.84	2.00	0.83
4	1.65	0.89	1.60	0.88	1.57	0.87

TABLE No. 25.

SAND AND CEMENT, BOTH LOOSE.

Cement weighs 60 lbs. per cubic foot.

	By Volume, Barrels of Cement.				By Weight, Barrels of Cement.			
	265 lbs.	280 lbs.	300 lbs.	Cu. Yds. Sand.	265 lbs.	280 lbs.	300 lbs.	Cu. Yds. Sand.
1	4.08	3.86	3.60	0.67	5.21	4.93	4.60	0.51
2	2.49	2.36	2.20	0.81	3.66	3.46	3.23	0.72
3	1.77	1.68	1.57	0.87	2.72	2.57	2.40	0.80
4	....	....	....	....	2.15	2.03	1.90	0.84

The above, while being very valuable as showing actual amounts of mortar to be obtained from the different mixtures of cement and sand, also emphasizes the importance of the unit to be used; as, taking the barrel of cement at 265 lbs. and the proportion of one part cement to two of sand, the tables give the following weights of cement for a cubic yard of mortar by each of the different methods:

	Pounds.
By volume, cement loose	660
By volume, cement packed	750
By weight	970

The second method requires 13½ per cent and the third almost 50 per cent more cement than the first. The plain and true inference is that the only sure way of knowing just how much cement is being used is to determine proportions by weight, or to specify that a cubic yard of mortar shall receive so many pounds of cement. This is particularly important now when so many manufacturers deliver their cement in bags by weight, and allowing a certain number of pounds for a barrel. When heavier cements, as the Portlands, are used, it is evident that there will not be so much difference in the methods employed.

Cement mortar is often used in sea-water, and in preparing it considerable extra expense would be incurred in providing fresh water for the mixture. Quite a number of experiments have been made at various times and by different persons to determine the action of salt water, if used in mixing, and also when the mortar is immersed in it.

Gen. Gillmore made some rectangular parallelopipeds of mortar 2×2×8 inches in vertical moulds under a pressure of 32 pounds per square inch until set. These were broken on supports from a pressure from above midway between the supports. The specimens were kept in a damp place for twenty-four hours, when they were placed in sea-water, where they remained ninety-four days, till broken. Table No. 26 gives his results.

TABLE No. 26.

Conditions.	Breaking Strength in Pounds.	No. Broken.
Neat cement mixed with fresh water	499¼	8
" " " " sea-water	379¼	8
Cement 1, sand 2, by volume mixed with fresh water	319¼	5
" " " " " " " " sea-water	195	4
Cement 1, sand 2, by volume mixed with sea-water, concentrated by heat 25 per cent	165	2

In the report of Mr. E. C. Clarke previously referred to Table No. 27 is given, showing the results of his investigations on this question.

TABLE No. 27.

Figures indicate tensile strength per square inch.

	Rosendale. 1 Cement, 1 Sand.				Portland. 1 Cement, 2 Sand.			
Mixed with...........	Fresh	Fresh	Salt	Salt	Fresh	Fresh	Salt	Salt
Immersed in.....	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt
1 week..................	40	48	50	61	151	122	152	149
1 month	126	135	114	126	218	191	203	200
6 months..............	247	250	243	224	314	245	277	264
1 year	310	263	224	217	342	231	346	292

Mr. A. S. Cooper in a paper published in the *Journal of the Franklin Institute*, October, 1899, details some experiments made by him, shown in Table No. 28, to determine the effect of salt water. The briquettes were the American Society of Civil Engineers' forms, the proportions being determined by weight. They were stored in moist air for twenty-four hours and then in an immersion-tank till broken. The figures represent tensile strength per square inch in pounds.

TABLE No. 28.

PORTLAND CEMENT. STANDARD SAND.

	1 Part Cement, 1 Part Sand.				1 Part Cement, 2 Parts Sand.				1 Part Cement, 3 Parts Sand.			
Mixed with ...	Fresh	Fresh	Salt	Salt	Fresh	Fresh	Salt	Salt	Fresh	Fresh	Salt	Salt
Immersed in..	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt
7 days..	544	568	585	618	487	477	458	492	278	329	303	270
28 days........	574	709	621	631	560	586	507	554	335	376	390	348
3 months.....	671	670	801	660	584	600	580	583	488	392	391	400
6 months.....	833	708	820	610	627	637	630	589	444	397	408	408
1 year........	846	625	819	818	587	471	614	478	431	282	344	385
NATURAL CEMENT. STANDARD SAND.												
7 days........	266	320	287	298	147	177	184	188	65	92	87	110
28 days........	310	381	297	384	250	256	218	248	107	150	120	164
4 months.....	385	369	400	414	296	322	335	325	223	228	230	282
6 months.....	377	388	370	368	298	325	332	334	221	223	238	237
1 year.... ...	305	299	356	275	235	170	207	191	200	162	173	140

While the actual figures given by Mr. Clarke and Mr. Cooper vary much as to the actual strength, owing doubtless to the character of the cement and the method of manipulation, they are relatively the same, there being a marked decline whenever the briquettes are immersed in salt water, especially the long-time tests with the Portland cements. Where the mixing is done with salt

water and the immersing in fresh, the difference is not so striking. Although these tests show that cement mortar is weakened by the action of salt water, works have been carried on of sufficient time and extent to make it certain that the deterioration is not dangerous. This becomes important in studying the action of frost on mortars, as it is customary to add salt to the water for mortar-mixing, when it must be used at low temperatures.

Mr. James J. R. Croes gives as a rule: "Dissolve 1 pound of rock salt in 18 gallons of water when the temperature is at 32° F., and add 3 ounces for every 3 degrees of temperature." He adds that masonry laid with such mortar stood well and showed no signs of having been affected by the frost.

Mr. Alfred Noble states that a pier was built on the Northern Pacific Railroad near Duluth at a temperature varying from 0 to 20°. Portland cement was used for the mortar in proportions of 1 to 1½ for face stone and 1 to 2½ for backing. Salt was dissolved in the water, and the sand was warmed. The mortar froze very quickly, and several months afterwards was found to have perfectly set and to be in as good condition as that laid in milder weather.

Table No. 29 gives the result of some of his experiments to determine the effect of salt upon the mortar, and Table No. 30 the combined effect of salt and freezing.

The amount of salt seems to make no material difference, although the figures are slightly less for the greater quantities, and, as in the previous tables, the salt water gives poorer results than the fresh.

These figures show some gain when salt water is used for the mixture and the briquettes immersed in fresh, and decided increase when they were frozen for six days and immersed in water long enough to thaw, but not a sufficient time to gain an additional set. The table would be of more value if it extended over a longer period of time.

Table No. 31 is taken from a paper read before the Canadian Society of Civil Engineers in February, 1895, by Prof. Cecil B. Smith of McGill University.

Set No. 1 was submerged, after 24 hours, in water of laboratory tank.

TABLE No. 29.

Proportions: cement 1, sand 1, volume; cement 21 ounces; sand 23 ounces; water 6 ounces. Figures are tensile strength per square inch.

Salt.	7 Days.	30 Days.	90 Days.	6 Months.	9 Months.	12 Months	18 Months	2 Years.
0 oz.	155	220	289	[illegible]	390	[illegible]	402	430
¼	139	200	246	288	363	364	[illegible]	346
½	139	192	231	289	[illegible]	383	392	[illegible]
1	128	189	217	288	343	369	350	384

TABLE No. 30.

PORTLAND CEMENT.

Mixture: cement 35 oz., water 7 oz., salt as shown.

Salt in Ounces.	0	⅛	¼	[illegible]	[illegible]	[illegible]6	¾	⅞	1
Immersed in test-room when removed from moulds..................	327	357	375	3[illegible]	[illegible]	[illegible]2	415	388	402
Exposed to air and frozen three days, then immersed in test-room four days	316	378	411	3[illegible]	[illegible]	[illegible]5	392	383	409
Immersed in test-room when removed from moulds.........................	386	422	421	399	394	384	390	356	387
Exposed to air and frozen six days, then exposed to air in test-room at 70° one day.	169	198	167	[illegible]	[illegible]	[illegible]	221	221	289

TABLE No. 31.

Mixture.	Age.	No. 1.	No. 2.	No. 3.	No. 4.	Temperature of Exposure of No. 3.	Temperature of Exposure of No. 4.	No. of Tests.	Remarks.
Portland neat	2 Mos.	602	471	282	331	+23°F.	+22°F.	16	....
1 to 1	"	277	275	194	233	+ 5°	+3½°	20	. ...
2 to 1	"	168	150	105	111	- 1°	0°	24	....
3 to 1	"	104	85	92	[illegible]	− 5°	− 6°	24	3 and 4 showed irregular and injured fractures.
Natural neat	"	236	221	349	0	+ 2°	+ 5°	24	4 completely blown in fragments.
1 to 1	"	125	229	167	44	+ 8°	+0.6°	22	Some of No. 4 injured.
Neat	"	250	261	159	94	+18°	+ 5°	24	Mixed with water at 122°F.
1 to 1	"	120	170	80	117	+ 9°	0°	20	Mixed with water at 118°F.
Neat	1 Month	155	278	217	249	+17°	+7½°	20	Mixed with 2% of brine.

Set No. 2 was kept on damp boards in a closed tank for the whole period, and never allowed to dry out.

Set No. 3 was allowed to set in the laboratory, and then exposed to the severe frost and left in open air for the whole period.

Set No. 4 was exposed in from 8 to 10 minutes to the severe frost and left there for the whole period.

The important deductions from the Portland tests are: 1. That mortar immersed in water is stronger than when used in air; 2. That mortar exposed to temperature below freezing and kept there till set is stronger than when allowed to set in air and then exposed to frost; 3. That mortar kept in damp air was the weakest of all the different conditions experimented on.

It will be noticed from the results of the tests of the natural cement: 1. That, contrary to the Portlands, these cements should not be used if the mortar must be exposed at once to frosts; 2. That from the neat tests no time deductions can be made of a sand mixture, as in every case when mixed with fresh water the 1-to-1 compound was considerably stronger than the neat; 3. That No. 2 in every case but one was the strongest, while with the Portland it was the weakest; 4. That the addition of salt to the mixing water added very materially to the strength of the briquettes when exposed to the frost.

Table No. 32 gives the results of some experiments made by Mr. A. C. Hobart and published in *The Technograph*, No. 12, 1897–98.

In all cases the briquettes were frozen six days after having been allowed to set, as shown in the table. They were thawed from 18 to 20 hours and then broken. The upper line of figures for each mortar is the strength in pounds per square inch of the unfrozen briquettes, and the lower is the percentage of the strength frozen to the strength unfrozen.

Table No. 33 gives the result of some tests made on 12-inch concrete cubes by Mr. W. A. Rogers, Assistant Engineer of the Chicago, Milwaukee, and St. Paul Railway at Chicago. "Atlas" Portland and Louisville natural cements were used. The proportions were: Atlas, 1 cement, 3 gravel, and 4 broken stone; and Louisville, 1 cement, 2 gravel, and 4 broken stone. Eight cubes were made of each cement, two being mixed with water to which

TABLE No. 32.

Portland.	Age in Hours when Frozen.									
Brand	1	2	3	6	12	24	48	72	168	336
Dufassey neat	321	337	341	372	374	400	352	379	327	672
	68	72	73	79	80	80	67	69	52	100
1 to 1	133	177	172	172	184	186	187	193	296	331
	58	77	75	75	80	79	75	75	105	102
2 to 1	33	43	62	58	79	81	82	103	181	209
	26	34	48	45	62	63	60	75	100	114
3 to 1	00	00	10	14	19	28	37	48	106	134
	00	00	8	18	25	37	47	58	103	93
Saylor's American neat	285	238	234	268	284	248	240	300	590	671
	60	50	50	59	50	45	56	110	110	105
1 to 1	144	176	173	175	179	255	260	271	303	391
	47	57	56	57	58	79	79	82	68	87
2 to 1	61	81	96	102	129	143	138	146	161	226
	55	73	86	92	116	129	120	108	98	128
3 to 1	18	26	15	33	48	54	69	74	87	124
	32	46	27	59	86	96	113	114	121	125
Natural.										
Clark's Utica neat	120	116	127	152	163	143	135	140	154	199
	90	87	95	114	122	107	79	80	70	89
1 to 1	114	118	111	128	131	142	137	107	138	160
	88	91	86	99	102	110	105	80	100	81
2 to 1	45	60	80	83	74	43	45	49	69	77
	71	95	127	132	117	68	71	70	83	91
Louisville Star neat	145	135	148	156	151	153	150	133	150	153
	109	102	111	117	117	115	93	81	81	79
1 to 1	136	139	130	164	141	130	120	108	123	137
	132	135	126	159	137	126	114	97	100	92
2 to 1	96	104	106	123	106	69	57	64	80	92
	133	144	147	171	144	96	98	88	107	93
Akron neat	108	112	109	184	156	150	142	140	132	150
	83	86	84	142	120	114	103	105	93	97
1 to 1	71	69	143	152	160	133	131	129	127	138
	79	76	159	167	176	148	146	137	130	115
2 to 1	57	70	83	87	85	80	80	72	65	60
	168	206	244	256	250	235	222	189	108	82
Louisville Black Diamond neat	116	173	175	191	228	237	228	216	182	163
	72	107	109	119	138	138	132	126	104	93
1 to 1	108	152	168	173	220	202	185	179	171	185
	94	132	148	150	191	176	158	127	91	93
2 to 1	63	76	79	93	101	120	104	78	69	90
	170	205	213	251	273	316	297	186	157	120

one pint of salt to ten quarts of water had been added, and the others with fresh water.

Capacity of machine 185,000 pounds. *a* showed signs of failure, *b* showed no signs of failure. The cubes kept out of doors were subjected at once to a temperature considerably below zero. During

TABLE No. 33.

Conditions of Cube after having been Made.	Age in Days.	Kind of Water.	Atlas.	Louisville.
Kept in warm office	28	Fresh	*a* 185,000+	43,000
Kept out of doors	28	"	115,000	33,000
Kept out of doors 28 days and in office 28 days	56	"	*b* 185,000+	52,500
Kept out of doors	28	Salt	*b* 185,000+	35,000

this exposure the weather was the coldest experienced in Chicago for twenty years, but subsequently grew warmer, so the cubes froze during the night and thawed during the day. The deductions the author of the paper makes for the mixture is: "Freezing before setting does not seem to injure the Portland-cement concrete even if, after having frozen hard, the concrete is exposed to freezing and thawing weather. Exposing green Portland cement concrete to a freezing temperature seems to affect its rate of hardening, making it slower, but eventually the concrete will be just as good as if it had not been exposed to the cold. The use of salt seems largely to counteract the effect of cold in causing slow hardening." He also makes the same deductions for Louisville cement, except that he thinks the use of salt seems to have little if any effect on the strength of the cubes exposed to the cold.

Mr. Noble describes the construction of an anchor-block of concrete. This was built during freezing weather, a portion of the time below zero, with about one-half of the mass below water. The mixture was 1 part Milwaukee cement, 2 parts sand, and 4 to 5 parts broken stone. The material and water were heated, a double handful of salt being added to each part of water. Ice formed over the top of the concrete every night until the mass was above the water-level. No attempt was made to protect the concrete from frost, and six months after it was laid it was found to be thoroughly set.

These experiments cover quite a period of time and were made by different people under very different conditions. As a rule the same general deductions can be made from them. That is, that with proper precautions good results can be obtained by the use of cement mortar in cold weather; that a freezing temperature

greatly retards the setting of mortar, but does not seriously injure it if properly treated; that it is much safer to use Portland cement in cold weather, especially if the mortar is to be subjected to alternate freezing and thawing. The one exception to the latter conclusion is the experiments of Mr. Hobart. His results would show that the American cements are not only influenced less by freezing than the Portlands, but that their strength is actually increased. Mr. Hobart says that this is so different from all the former ideas on the subject that some of the tests were carefully duplicated with practically the same results.

Specifications for work involving the use of cement mortar always provide that it shall be used within a certain time after it has been mixed, generally from half an hour to an hour and a half, according to the character of the work and the nature of the particular cement. This is because it is considered that cement mortar should be in its permanent place before it has begun to set, and that any disturbance after the first set reduces its ultimate strength. Not many experiments have been made to demonstrate this, and it can be readily understood that to be of value tests must be made of each individual cement. A slow-setting cement will of course permit more manipulation and disturbance than one that sets quickly, and just what the effect will be can only be known by experiment. Table No. 34 shows the result of some experiments detailed by Gen. Gillmore. The sections used and the methods of constructing and breaking were the same as on page 121, except that the mortar was made of equal parts of natural cement and sand by volume, and the samples were kept in sea-water for 320 days.

TABLE No. 34.

	Breaking Strength.
Cement fresh from barrel, average of five	767 lbs.
" repulverized after 3 days' set, average of six	236½ "
ANOTHER BRAND.	
Cement fresh from barrel, average of four	631 lbs.
" repulverized after 3 days' set, average of ten	261 "

Table No. 35 gives the results of Mr. Cooper as published in the paper previously referred to. The briquettes were made of Portland-cement mortar mixed 1 : 2 and broken at the end of one

year. The figures represent tensile strength in pounds per square inch, and the different columns show the time of making the briquettes after the mixing of the mortar.

TABLE NO. 35.

Kind of Sand.	Per Cent of Water.	Made when Mixed.	Number of Hours Made after Mixing.							
			1	2	3	4	5	6	7	8½
B ach....	14	232	248	227	211	....	....	....	....	....
"	9.7	182	181	172	176	....	..	..	...	...
"	15.3	240	230	245	227	..	[illegible]		22[illegible]	236
River....	13.9	244	238	194	....	24[illegible]	..	259	23[illegible]	

The author of the paper concludes: " In practical working with most Portland cement, if it becomes necessary for the mortar to stand for one-half of a day even, no injury will result, provided the precaution is taken to keep the mortar wet."

Another test to which cements are generally put is the one for maintaining its volume. This is sometimes done by placing the mortar in a cylinder of glass. If any expansion takes place in setting, the glass will be broken, and if any shrinkage, it can be easily detected. Mr. Clarke says in the Boston Main Drainage Report that in his tests the cylinders were invariably broken. Another method is the so-called " hot water " test. The Faija method is to mix a small pat of cement with as little water as possible, and place it on a glass plate in a covered vessel which contains water maintained at a temperature of about 112°. The pat is kept in the moist air for 6 or 8 hours, when it is immersed in water kept at a temperature of from 115° to 120° Fahrenheit for the remainder of 24 hours. If at the end of that time it remains intact with no signs of disintegration, it is ready for use. Manufacturers, however, can overcome the effect of the heat by adding sulphate of lime to the cement. In speaking of hot-water tests, Mr. Cummings in his work heretofore referred to says: " It is safe to assert that of the more than one hundred and fifty million barrels of American rock cements used in all of the great engineering works throughout the country during the past fifty years, and with no evidence of failure, not one per cent would have sustained the boiling test. A cement, whether natural or artificial, that will crystallize so rapidly as to sustain the boiling test ought to be looked upon with

suspicion, as it is either naturally too quick-setting or too fresh and lacking in proper seasoning."

Concrete.

Concrete can be defined as masonry made up of broken stone, gravel, cinders, or other similar material, joined together by cement mortar. It has been in use for centuries. One of the oldest and most noted examples of concrete construction is that of the dome of the Pantheon at Rome. In early times it was used principally for foundations. But as its value has become recognized and cement has been produced better and more cheaply, its use has been extended until now it is put to practically as many uses as is stone itself. It is used as a monolith and also in blocks. It is particularly adapted to foundations of irregular form, as it is cheaply and easily shaped. It is used extensively in foundations for all classes of work, bridge piers and abutments, sidewalks, curbing, sewer-pipe, fire-proof floors, and even as a monolith in arch bridges of quite extensive spans. Stone suitable for concrete is often found in localities where good building-stone is not obtainable, and thus the use of concrete allows masonry construction when the cost of natural stone would have been prohibitive. So it is not strange that it has become popular with engineers, as, when well made, its success has always been as great as its adaptability.

Probably no one thing has increased the consumption of Portland cement to so great an extent as has the use of reinforced concrete. By this device it is possible to use concrete in almost all kinds of construction, from bridges of two or three hundred feet span down to tables and railings for platforms and bridges. Concrete is used also to a great extent in the construction of large dams. It is used in great quantities in the construction of buildings, both large and small, and in fact its use and the consequent increase in demand for Portland cement seem almost illimitable.

In specifying proportions for concrete-mixing, it is customary to regulate them in units of cement. This is not the true way, and there is a growing tendency among engineers to change this and establish instead a certain quantity of mortar as standard unit. The province of the mortar is to bind the pieces of stone together, and when the voids of stone are positively filled, any excess is simply wasted. In deciding, then, upon the proportions to be used in the

concrete, the amount of voids in the stone adopted must be first ascertained. This will vary with different kinds of stone and according to the uniformity with which it is broken. The actual size of the stone does not make so much difference. When the pieces are approximately cubical and of about the same size, the voids will be about 50 per cent of the stone. By grading the sizes, however, from the largest to a permissible minimum, the amount of voids can be materially reduced, thus accomplishing a saving of mortar and increasing the strength of the mixture. In order to insure the complete filling of the voids and making as solid a mass as possible, it is best to specify an amount of mortar, about ten per cent in excess of actual voids, as perfect work is very seldom attainable in practice.

The exact composition of the mortar is important. The character of the work must determine the strength required for the concrete. Recognizing, then, that a concrete cannot be stronger than its mortar, the proportions of the concrete and sand can be decided upon. For a good concrete, stone should be hard, tough, and of such a texture as to permit of strong cohesion between the mortar and the different fragments. But it would not be allowable, or good engineering, to go to great expense to provide a stone that would be appreciably stronger than the mortar matrix. The ideal concrete would have its stone and mortar of equal strength, so that when broken the fracture will extend through mortar and stone alike. Clean gravel and gravel mixed with broken stone have been used with great success. In concrete for fire-proof floors, where weight is an important consideration, clean steam cinders are generally employed. This gives good results, and some of the tests of very flat arches made of this material show that its strength is surprisingly great.

After having determined upon the amount and composition of the mortar required for any given amount of stone, the next step is its preparation. The sand and cement should first be thoroughly mixed dry. The importance of this cannot be overestimated. Without good mortar good concrete cannot be obtained. It is not sufficient that enough and good materials are provided, but they must also be properly applied. Water should next be added in such quantity as will assure the desired consistency, without drowning out the cement, and the entire mass mixed rapidly until

every grain of sand is coated with cement, as this acts with the sand in precisely the same manner as the mortar acts with the stone. It is miniature concrete. As it is desirable to have as great cohesion as possible between the mortar and the stone, the latter should be thoroughly wet, so as to wash off all dust or other foreign matter, and then added to the mortar.

The resulting mass must then be turned over forward and backward until the mortar is scattered evenly among the interstices of the stone, so that each piece is completely covered and the concrete is finished. The material at all times must be kept on boards or platforms, so that it shall be kept free from all foreign matter. This operation of mixing should be done without delay and as expeditiously as possible, as the sooner the concrete is in place the more complete will be its final set. The place of mixing should be near its final location, preferably so that it can be shovelled to it from the boards; but this is seldom possible, and it must be carried in some conveyance and dumped. When used in any great mass it should be spread in layers from 9 to 12 inches in depth and at once thoroughly tamped till the mortar flushes to the surface, and then left undisturbed till completely set, or till another layer is ready to be placed upon it. In such work it is better to have one layer follow another before the first has entirely set, so that they can become thoroughly bonded together. Whenever fresh material is placed upon or against old that has become dry and hard, the latter should first be wet in order to aid in this bonding.

The amount of materials of the different kinds necessary to produce a given quantity of concrete is important. Enough has already been said to show upon what this is conditioned. Whether it will be economy to mix gravel with the broken stone if that be used, or whether one or the other is to be adopted, depends upon the ease with which they can be obtained and their relative values. It is the business of the engineer to study this question till it can be correctly settled. Having then determined upon the aggregate, and the amount of voids it contains, the amount of mortar is at once decided upon. Ordinary sand contains loose about 37½ per cent of voids. Some tests to determine this, made in the laboratory of the Department of Highways, Borough of Brooklyn, New York City, resulted as follows:

		Per cent.
Street sand:	sample No. 1, compact, voids.......	28.3
	sample No. 1, loose, voids..........	37.6
	sample No. 2, " "	35.0
	sample No. 3, " "	37.5
Standard sand:	compact, voids.................	44
	loose, "	52.75

Mortar mixed with No. 3 in the proportion of 1 cement to 2 sand and tamped into a mould till the water flushed to the surface gave a resulting volume of 2.07 parts, showing but little increase over the original bulk of sand. A similar mortar mixed with four volumes of 1-inch broken stone, very uniform in size, in which the voids had been found to be 51 per cent, thoroughly tamped as before, produced a volume of 4.04 parts of concrete, although it was discernible to the eye that all the voids had not been filled.

In Paper No. 855 of the American Society of Civil Engineers will be found much information on concrete. Mr. Geo. W. Rafter made many experiments to determine the actual amount of mortar and concrete obtained with different proportions of sand, cement, and broken stone. The experiments were made with dry, plastic, and excess mortars. The results are given in Table No. 36 for plastic, as that is the consistency which would be the most liable to be used in actual work. Slightly different amounts were obtained with different brands of cements, and the mean is given.

TABLE No. 36.

Parts Cement.	Parts Sand.	Mortar.	Stone.	Concrete.	Mortar Percentage of Stone.	Shrinkage of Stone, per cent.
1	1	1.83	5.51	5.01	33	9.1
1	1	1.66	4.14	3.82	40	7.7
1	2	2.45	7.28	6.62	33	9.1
1	2	2.50	6.28	5.83	40	7.1
1	3	3.30	9.92	8.89	33	10.4
1	3	3.31	8.23	7.62	40	7.3
1	4	4.28	12.94	11.66	33	9.9
1	4	4.35	10.96	10.09	40	8.0
1	5	5.04	15.05	14.29	33	8.3

From these amounts of mortar it would seem that the sand used must have been very compact, containing very few voids, as the 1-to-1 mixture increased 83 per cent over the volume of sand, while the 1-to-5 even had a slight increase in volume. The resulting volumes of concrete, on the other hand, indicate a large amount of voids in the stone, as in every case there was a material decrease in the original volume of stone used.

In a discussion on the above paper, Mr. Wm. M. Hall gives the voids found by him in sand, gravel, broken stone, and the two last combined in different proportions.

TABLE No. 37.

SAND 31 PER CENT., ITS SIZE BEING AS FOLLOWS:

	Per cent. by Volume.
Held by a No. 20 sieve	11
Passed by a No. 20 and held by No. 30	14
" " " 30 " " " " 50	53
" " " 50	22

CRUSHED STONE AND GRAVEL AND MIXTURES OF THE TWO.

	Voids.
100% of crushed 2½-in. stone	48%
80 " 2½ " " 20 of 1½-in. gravel	44
70 " 2½ " " 30 " 1½ " "	41
60 " 2½ " " 40 " 1½ " "	38½
50 " 2½ " " 50 " 1½ " "	36
100 " 1½ " "	35

TABLE No. 38.

	Sand.	Sand-stone.	Boulder Stone.	Gravel.	Furnace Slag.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Passing 1½-inch ring	....	100	100	100	....
Retained on 1-inch ring	....	100	100	10.70	....
Retained on ⅜-inch ring	....	....	....	23.65	1.10
Retained on No. 4 sieve	....	....	....	8.70	2.86
" 10 "	....	....	....	17.14	45.62
" 20 "	4.17	....	....	21.76	36.92
" 30 "	12.52	....	....	6.49	8.26
" 40 "	44.44	....	....	5.96	3.24
Passing No. 40 sieve	38.87	....	....	5.99	2.00
Voids	41.7	45.3	48.7	34.08	43.8

The dust had been screened out of the stone, and the sand from the gravel. The slight difference in voids between the last mixture and the gravel alone would indicate that the limit of the reduction in voids had been practically reached.

Mr. H. Von Schon, in further discussing this same paper, gives among others a table showing voids found in different materials, and how they were graded as to size. This is reproduced as Table No. 38.

So much attention has been given to voids, as it is absolutely necessary to know the space to be filled by the mortar in order to get the best concrete, as well as to tell how much will be obtained from a given mixture. The amount of tamping it receives will also affect the quantity materially up to the point of filling the voids.

The proper consistency for a concrete mixture is a question that has been much discussed by engineers. As it requires much less labor to mix it when an excess of water is used, contractors and laborers always have a tendency to add as much as permitted, and constant restraint is required to restrict them. The general theory is that a medium dry concrete will be stronger than one mixed with more water. This is probably true theoretically, and would most likely be borne out in tests; but it must be remembered that such a mixture would require much more tamping to become thoroughly compacted than one more plastic, and also that extreme vigilance is necessary in order to obtain it; also that the mixing itself will not be so evenly done if dry. Then, too, if the concrete is spread out in thin layers, as is done in the case of foundations for street pavements, a portion of the water will be evaporated before it has had a chance to combine with the cement, and the mortar will simply dry out rather than set. This is particularly the case in hot weather; and although the tendency can be somewhat overcome by keeping the concrete wet by sprinkling, the results will not be as good. The author was brought up in the dry school, but his own experience has taught him that it is safer to have the mixture a little wet rather than a little dry. The immediate result is to retard the setting, but as time passes its strength increases, and it is very doubtful if it be appreciably weaker at the end of a few months. The ratios for strength of the different concretes made

by Mr. Rafter were: dry mortar 29.1, plastic 26.6, and excess 25.3, taking the average of ten tests.

The experience of the last few years, especially in reinforced concrete work, where it is absolutely necessary that the voids should be filled, has demonstrated the fact that a wet rather than a dry mixture should be used. This would undoubtedly be true of pavement foundations, but care should be taken that it is not carried to such an extreme that it will not hold its shape after having been deposited on the street.

Concrete is often mixed by machinery, and much discussion has arisen over the value of this method as compared to hand mixing. Much can be said on both sides. Many machines have been devised for this purpose, and varying results will be arrived at with each. In hand mixing the cement and sand should be first measured out in the proper proportions and then carefully mixed dry on a smooth platform. Enough water should then be added to make a mortar of the desired consistency, when the whole mass should again be mixed. The first requisite is to have a good mortar. Whatever the aggregate to be used, it should be free from all dust or sand and thoroughly drenched, so that it shall be clean and damp in order that the mortar will readily cling to it. The mortar should then be spread upon the board and the stone added. Workmen should then proceed with the mixing, working from the bottom and throwing all material from the centre to the sides, turning their shovels downward in so doing. It should then be all thrown back in the same manner, forming a pile in the centre. If this be carefully done, the stones are generally all coated and the concrete should then be placed in its permanent position. If the work is well carried out, there will be no question but that good results will be obtained.

There are many kinds of machines for mixing concrete. A machine for use in laying foundations for pavements should, if possible, have a continuous discharge. There are several of these machines in use, one of which, Fig. 3, consists of the ordinary machinery for a batch mixer mounted on wheels, equipped with an end-loading bucket holding the full capacity of the drum, a water-measuring tank which supplies the water for each batch, and a water tank mounted on the frame to supply water for the

FIG. 3.

FIG. 4.

boiler. The machine is mounted to discharge at the rear instead of at the side. It is provided with a traction drive for moving it along the street, enabling it to be also kept at the exact location for the most rapid work with the least handling or hauling of materials. This allows the supply piles to be made continuous along the sides of the street and the mixer placed in the center between the piles and moved along as conditions require; the mixer can also be kept in the most convenient place for the supply of materials and delivery of concrete. The concrete is sometimes taken from the mixer in barrows. But the machine is equipped with a concrete delivery boom and bucket, into which the concrete is discharged from the mixer, and then the bucket travels out along the beam to its point of delivery. This I-beam is connected with the frame by a universal joint, which allows it to swing from one side of the street to the other in an arc of 180 degrees, and, as the beam is 20 feet long, it will cover a roadway 40 feet in width. The bucket holds a full batch of the mixing drum, and is provided with an automatic dump so that the bottom gates open automatically at any place where it is desired to deposit the concrete. The bucket then returns to the mixer, the gates closing automatically, and the clutch disengages so that the bucket is left in position under the discharge chute.

Another type, Fig. 4, consists of the regulation mixer, mixing drum and power machinery mounted on wheels. This machine is charged from the rear by means of two scoops, each of which has a capacity of 8 cubic feet. The scoops are simultaneously pulled up an incline, discharging automatically into the mixer chute. A traction drive forms part of the apparatus. The mixer is arranged for rear discharge. The mixer itself delivers the concrete into a distributing cylinder consisting of a steel pipe 15 feet long, suspending horizontally, with a fall of about 6 inches, and revolving by means of sprockets and sprocket chains; and blades riveted inside the cylinder keep the concrete constantly in motion towards the end of the device. The cylinder swings in a radius of 180 degrees, enabling the operator to cover any point in a 30-foot street. The concrete is thus placed exactly where required, dispensing with cars, carts, wheelbarrows and other distributing devices. The distributing cylinder also contributes

materially to the mix, as the mixing action continues while the materials are traveling through the distributor. It is claimed that with this machine a gang of sixteen man can lay 1,000 square yarbs of 6-inch concrete per day.

Still another which has been used much in Brooklyn on street work is a portable machine shown in Fig. 5. The boiler and mixer are mounted on four low wheels and can be moved by a pair of horses as the work progresses, or by the men on the street. It consists of a square shaft running lengthwise of a horizontal semi-cylinder about 28 inches in diameter and 8 feet long. The cylinder is firmly set in a frame. To the shaft are attached cast-iron blades of such length as will give a little space between the ends and the cylinder, and at an angle inclined to the shaft so that as it is revolved the material moves towards the end. If it move too freely, so that it reaches the end before it is thoroughly mixed, a few of the blades near the centre can be reversed, thus checking the forward motion. Water is supplied by a perforated iron pipe running along one side and connected by hose to a hydrant, the amount being regulated by a stop-cock. A little room is left near the end to allow about a wheelbarrowful of concrete to accumulate, when the end gate is raised and the concrete dumped into the waiting barrow and then wheeled to any desired location. At the other end of the machine the boiler and engine are located. When the machine is operated continuously the boiler requires about one-half ton of coal per day, the same man acting as engineer and fireman.

To operate it to advantage, the machine is located in the centre of the roadway and the broken stone dumped upon planks upon one side and the sand and cement on the other. The latter are carefully measured out and mixed dry in a long pile on a continuous platform. Men with shovels are stationed on each side, the number corresponding to the proportion of mortar and stone desired, and throw the material towards the back end of the shaft so that it may have the benefit of all the blades in the mixing. As the shaft revolves the mass moves forward according to the speed of the engine and the pitch of the blades. As the concrete falls into the wheelbarrow an experienced foreman or inspector can readily detect if it be not properly mixed and apply the remedy, so that in a very short time the machine will be operating success-

Fig. 5.

fully. No attempt is made to measure the stone, as it can be told by inspection whether sufficient mortar is present to fill thoroughly the voids, and that is all that is necessary. If too much or too little mortar is being used, the trouble is remedied by adding to or taking from the men at work on the stone as the occasion requires. This machine has a capacity of about 150 cubic yards of concrete per day when running smoothly under a capable foreman.

As to the question whether concrete mixed by hand is better than that mixed by machine, it can be said that the product of either is good when properly made, and that incompetent workmen will spoil both. Mixing mortar and stone is hard work, and laborers will shirk it whenever possible; so that if proper systems are adopted for obtaining and applying the right proportions, it would seem that concrete mixed by machinery ought to give more uniform results than that mixed by hand.

In the preceding pages some examples have been given of quantities of concrete obtained from certain mixtures of cement, sand, and stone in the laboratory, so that it will be of interest to know of some of the results in actual work carried out on a large scale. It must be understood that different-sized barrels, different kinds of sand, and the varying amount of voids in the broken stone used will materially affect final results.

In making concrete for dam No. 11 on the Great Kanawha River Improvement, eleven batches, each containing 2 barrels of cement, 15 cubic feet of sand, and 33 cubic feet of broken stone, made 396 cubic feet or 14⅔ cubic yards of concrete when rammed in place. Assuming a barrel of cement to be equal to 3.75 cubic feet, this would make the proportions by volume 1 cement, 2 sand, and 4.4 broken stone, and would give an increase of concrete over broken stone used of 9.1 per cent. The amount of material used for one yard of concrete was 1½ barrels of cement, 11¼ cubic feet of sand, and 24¾ cubic feet of stone.

On a piece of work where 1000 barrels of Portland cement was used and the concrete mixed cement 1, sand 2, and 2½-inch broken stone 4, the average amount obtained was 20 cubic feet per barrel of cement. The broken stone was well graded in size, and the voids, though not determined, must have been small. This would be 1.35 barrels of cement for 1 cubic yard of concrete.

On two separate occasions the author had accurate records kept on street work where the concrete was mixed by machine in the proportion of 1 : 2 : 4, and in one case 97 barrels of cement made 81 cubic yards, and in the other 106 barrels of cement made 87 cubic yards of concrete, or almost exactly 1.20 barrels of cement per cubic yard. In these particular cases the parts of sand and stone were taken with the loose cement as a unit.

The author once laid a quantity of concrete mixed 1 : 2 : 5 in a shape and place where it was difficult to get exact measurements, and he was allowed by the engineers in charge ten per cent in excess of broken stone used.

In the discussion of the paper before the American Society of Civil Engineers, "On the Theory of Concrete" previously referred to, Mr. Allen Hazen gives some data on concrete mixed under his direction as follows: One barrel of cement, 30 pounds of water, 11.4 cubic feet of sand, and 19 cubic feet of gravel. The volume produced from the above was 22.7 cubic feet, or an increase in concrete over the gravel of about 20 per cent. On the entire work 15,085 cubic yards of concrete required 18,584 barrels of cement, or 1.23 barrels per cubic yard.

In a paper read before the American Society of Municipal Improvements Mr. C. H. Rust gave the amount of cement necessary to produce 260 cubic yards of concrete as 255 bbls., the mixture being presumably 1–3–6.

The increase in the consumption of cement in this country has been something enormous, as can be seen by reference to Table No. 39. This has been caused by the great demand for cement for construction purposes and the supply which immediately followed the demand. The large amount of Portland manufactured at so low a price has practically driven the natural cements from the markets, the amount produced in 1910 being less than 12 per cent of that made in 1899.

The Portland cement plants have increased to such an extent that in this country in 1910 they numbered 111, located in twenty-five states. They manufacture more cement than is used in the country, the exports exceeding the imports at the present time.

Engineers at first were skeptical as to the relative value of the domestic and imported products. But as the plants increased

in size and number, new supplies of material were found, improved machinery was installed, new methods of manufacture were invented, until now the American product is considered equal to the imported, and it can be produced at an extremely low cost, the price at the mills averaging in 1910 $0.891 per bbl., not including the package. This is as against $2.50 in 1880.

Table No. 39 shows the domestic production in barrels, and the imports of Portland cements, for comparison.

TABLE No. 39.

	1890.	1895.	1900.	1905.	1910.
Home product . .	335,500	990,324	8,482,020	35,246,812	76,549,951
Imported *	1,940,186	2,997,395	2,386,683	896,845	306,863
Exported.	. . . .	. . . .	100,400	897,686	2,475,957
Consumption. . .	. . . .	. . . .	. . . .	35,245,971	74,380,857

* Estimated about 5 per cent natural cement.

It can readily be seen how strong a hold American Portlands have on the market, when from 1896 to 1898 the imports fell off 975,779 bbls. and the domestic production increased 2,149,261 bbls. The value of the domestic product for 1898 was $5,970,-773, or about $1.62 per barrel.

Table No. 40 shows the amount of American natural cement produced from 1880 to 1910 inclusive, in barrels.

TABLE No. 40.

	Natural Cement.		Natural Cement.
1880	2,030,000	1899	9,868,179
1885	4,100,000	1900	8,383,519
1890	7,082,204	1905	4,473,049
1895	7,741,077	1910	1,139,239

A barrel is assumed to contain 300 pounds of natural or 380 pounds of Portland cement.

The total value of the natural product for 1910 was $483,006 or $0.433 per barrel.

Puzzolan Cement.

According to "The Cement Industry in the United States in 1910" this cement is defined as:

"Cement materials included under this name are made by mixing powdered slacked lime with either volcanic ash or a blast furnace slag. The product is therefore simply a mechanical mixture of two ingredients, as the mixture is not burnt at any stage of the process. After mixing the mixture is finely ground."

The following is the production of this cement, in barrels, in recent years:

1896	12,265
1900	446,609
1905	382,447
1907	557,252
1910	95,951

CHAPTER VI.

THE THEORY OF PAVEMENTS.

LORD MACAULAY said in his History of England: "Of all inventions, the alphabet and printing-press alone excepted, those inventions which abridge distance have done most for the civilization of our species."

Adam Smith once asserted that "the construction of roads is the greatest of all improvements." While these remarks had special reference to communication between towns or villages, they can with equal force be applied to cities and towns themselves. Some one has said: "Tell me the condition of the churches of a city, and I will tell you of the prosperity of that city." If this be true of churches, how much more truly can it be said of the pavements! Probably no one condition in a city strikes a stranger as forcibly as the general appearance of its streets. The clean and improved pavements of New York City during the last few years have impressed the rural visitor more than any one other feature of the city, the tall office-buildings, even, not excepted.

The word "pavement" comes from the Latin *pavimentum* and means "a floor rammed or beaten down"; hence the hard smooth surface of a street can be called pavement. It can be defined as the artificial surface of an improved roadway formed of hard or durable material for the purpose of facilitating travel and forming a presentable surface to a street at all seasons of the year.

There has been considerable discussion among engineers as to what really constitutes a pavement. Its importance can be seen when it is remembered that a great many cities compel abutting property owners to pay for the first pavement, but keep it in repair and renew it at the expense of the city at large. The people, knowing this, often make their first improvement as cheaply as possible.

leaving to the general public the task of effecting a real and permanent improvement.

Pavements have been laid of many materials, both perishable and imperishable, natural and artificial. The experience of one city has not seemed to benefit very greatly any other, but it has seemed necessary for each one to work out the problem for itself. This was especially true in earlier years, when there was less communication between city officials and when, too, there was less interest taken in the subject. At the present time the ideas of city officers are spread abroad through the medium of official reports, technical societies, and technical journals, so that one can easily know what is being done in outside cities by keeping in touch with these means of communication.

But it by no means follows that the decision as to what is the best paving material for one locality will necessarily govern in another, however intelligently it may have been reached. There are so many conditions affecting this question that it must generally be decided by their careful study in each particular case. For instance, stone may from its proximity and availability be just the material for one city and the cost of transportation make it prohibitive for another, and some other material must be used.

The value of pavements to a city or a particular neighborhood is positive and immediate. Real-estate owners, than whom no more shrewd or sagacious men are in business, recognize this, and when they wish to put a piece of property on the market at once and at good prices, always pave the streets with the most popular material. The pavement improves the appearance of the streets so much that the lots not only sell more rapidly, but the owner can add to his price more than enough to reimburse him for his outlay.

Of how much importance street pavements are in a large city can be understood only by a knowledge of their cost and extent. In the present city of New York there were approximately 2200 miles of pavements on January 1, 1912. Assuming the cost of a good pavement to be $2.50 per yard and the average width of a street to be 30 feet between curbs, the cost per mile, including curbing, will be about $55,000, making a total of $121,000,000 New York City would have invested if her street pavements were all of good character and in good condition. Or assuming that

each street must be repaved every twenty years, to keep the above mileage renowed when worn out will require the laying of 110 miles of street pavement each year. Assuming further that the average cost of repairs to all pavements will be nothing for the first five years, and five cents only per yard for the remainder of its life, the total annual expense for maintenance and repairs on the present mileage of New York City's pavements will be $880 per mile, or $1,452,000 for repairs and $6,050,000 for renewals, or a sum total of $7,502,000 per annum to keep the present paved streets of New York in good condition. Other cities will have less cost, but this illustration shows the necessity of careful study and investigation.

It will be of interest and value to know how these vast sums are raised; and while payments for all public improvements must come from the property owner, the methods of obtaining it vary much in their detail.

In a paper called "Theory and Practice of Special Assessments" read before the American Society of Civil Engineers by Mr. J. L. Van Ornum, the methods of paying for street improvements in fifty cities were given. Table No. 41 is compiled from this paper.

When special assessments are made against the abutting property different methods are adopted for payments. In certain sections of the West the tax is due in instalments, special bonds being issued to raise funds to pay the contractor, which bonds mature as the instalments are paid, and are not considered as a general indebtedness against the city.

In other places the entire amount is payable when the work is completed, tax certificates against the property being issued to the contractor as payment, and he being compelled to make all collections. In the East it is more common to make the tax payable after work is completed and assessment laid, funds being provided temporarily by the issue of stock of the city.

When the amount of money involved is so great, it is not strange that many inventors have been at work and many experiments made to determine what is the best material for pavements. As a result streets have been paved with stone in varied forms and shapes, wood, asphalt, coal-tar, cement concrete, iron, brick, india-rubber, shells, gravel, slag blocks, and even glass, leather, and hay; and

many of these in such modified ways as to make entirely different pavements.

TABLE No. 41.

City.	Grading, how paid.	Original paving, how paid.	Repaving, how paid.
Atlanta, Ga.	By city at large	⅝ by abutting property owners, ⅛ by city at large	⅝ by abutting property owners, ⅛ by city at large
Baltimore, Md.	All by abutting property owners	All by abutting property owners	
Boston, Mass	All by abutting property owners	All by abutting property owners	All by city at large
Cincinnati, O	2% by city at large, 98% by abutting property owners	2% by city at large, 98% by abutting property owners	As original, except when done by special act of legislature
Indianapolis, Ind...	All by abutting property owners	All by abutting property owners	All by abutting property owners
Louisville, Ky.......	All by abutting property owners	All by abutting property owners	By city at large
Milwaukee, Wis......	All by abutting property owners, except intersections, which are for paid for by city at large	All by abutting property owners, except intersections, which are for paid for by city at large	By the ward, except when on concrete foundation, then as original improvement
Minneapolis, Minn ..	By the ward	By the abutting property owners, except intersections, which are paid for by city	By the abutting property owners, except intersections, which are paid for by city
Newark, N. J........	All by abutting property owners	All by abutting property owners	All by abutting property owners
New Orleans, La....	¾ by abutting property, ¼ by city at large	¾ by abutting property owners, ¼ by city at large	¾ by abutting property owners, ¼ by city at large
New York City......	All by abutting property owners	All by abutting property owners	By city at large
Omaha, Neb.........	⅛ by abutting property owners, ⅛ by city at large	All by abutting property owners, except intersections, which are paid for by city at large	All by abutting property owners, except intersections, which are paid for by city at large
Philadelphia, Pa....	By city at large	All by abutting property owners	By city at large
Portland, Ore........	All by abutting property owners	All by abutting property owners	All by abutting property owners
St. Louis, Mo.	By city at large	All by abutting property owners	All by abutting property owners

Durability was thought to be of great importance, and iron was experimented with in several cities. It was once tried in St. Louis, but was soon taken up.

Iron blocks laid on Cortlandt Street, New York, about 1865, were roughened on the surface by hexagonal projections about one inch in size, separated by similar depressions. This made a rough and noisy pavement; horses tore off their shoes, slipped and fell frequently; so that after a short trial it was taken up and replaced with stone.

In 1885 some one suggested a hollow iron block 4 inches wide

and from 10 to 12 inches long, the hollow to be filled with any material that might seem fit.

In 1877 "iron paving" was laid on "Unter den Linden" in Berlin. It remained for quite a number of years, being removed about 1890 at the request of the experimenters. The same people, however, continued their work by paving the intersection of Langen-Strasse and Marcus-Strasse with impregnated wooden blocks capped with steel. The blocks were laid on concrete, and the joints filled with a bituminous preparation. An inquiry as to this pavement in 1899 elicited the following reply:

"The pavement which was laid down in the year 1888 by the United Königs- and Laura-Hütte in the Langen-Strasse at the junction of Marcus- and Holzmarkt-Strasse was removed in the summer of the year 1897, upon application of the makers, and has been replaced by asphalt pavement.

"Although the pavement had shown itself to be pretty durable in the beginning, it was, after an existence of about eight years, so worn out in its steel-capping in consequence of the heavy traffic, that it required a renewing of the latter, and an entire repavement became necessary.

"As from the beginning the building administration on account of the very high price—about twice as much as for asphalt pavement—doubted the wisdom of granting a further appliance of this wood-iron pavement, the company, who, as the party obliged to keep the pavement in good order, would have had to carry the cost of renewing, asked us to be relieved of this obligation.

"This request was granted by us, and as already stated above, after removal of the wood-iron pavement the same was replaced by a pounded asphalt pavement.

"It is hardly necessary to mention that the cost of the pavement in question would have been considerably increased by the present price of iron, which is almost 100 per cent higher than it was at that time."

Another plan was to set hollow iron cylinders closely together on a firm base and fill all interstices as well as the cylinders with concrete, the idea being that the iron would prevent the wear, and the concrete a general smoothness. It is doubtful if this idea was ever experimented with, even.

In 1890 a small piece of experimental pavement was laid on a sidewalk crossing in Columbus, O., at an entrance to a railroad freight-yard. An iron plate was cast with pockets $3^7/_{16}$ inches square on the upper side. Each plate contained five full, four half, and four quarter pockets so arranged that when set on the street the plates were square and the pockets at an angle of 45° with the length of the street. The plates were bedded on the foundation, and into the pockets were driven oak blocks five inches high and projecting two inches above the pockets. At the end of sixteen months the blocks showed a wear of but ¼ inch, when it is said that macadam within the freight-yard was renewed in ninety days, and asphalt outside was replaced in four months. This pavement would hardly be practicable, however, on a large scale.

About 1889 a so-called jasperite pavement was laid in Wichita, Kansas, the process being protected by letters patent. It consisted simply of a concrete made of Portland cement and the particularly hard stone found near Sioux Falls, South Dakota. The author talked at the time with the patentee, who was quite enthusiastic over his contract. The work amounted to several thousand yards, but never was a success, and was not repeated anywhere else.

About 1898 an experimental pavement of compressed marsh-grass was tried in Richmond, Va. The grass was first treated with a preparation of oil, tar, and resins, and then compressed with hydraulic pressure into blocks about 5 inches square and bound together with wire. The blocks were laid in the usual way on a street where they were subjected to very heavy traffic. The pavement lasted but a few months.

A pavement that is somewhat used in England where the traffic is light is called "tar-macadam."

A 10-inch bed of hard clinkers and broken stone is well rolled with a 12-ton steam-roller and covered with 4 inches of 2½-inch broken stone well rolled. Upon this is laid a 3-inch course of tar-macadam, consisting of one ton of 1½-inch granite to 12 gallons of tar, 28 pounds of pitch, and 2 gallons of creosote oil. This is well rolled and covered with an inch of limestone screenings mixed with the same cementing material, then covered with fine screenings and again rolled.

In certain portions of Germany a combination iron macadam is used for roadways. Common iron slag treated so as to lose some of its brittleness is broken into small pieces as nearly uniform as possible. It is then spread over the surface of the road and thoroughly rolled. Bog iron-ore is then scattered over it until it is covered, and the whole mass again rolled to a hard surface. Where the traffic is heavier, broken stone is used over the slag.

Artificial stone blocks have been made in Chemnitz as follows: Coal-tar is mixed with sulphur and warmed thoroughly. Chlorate of lime is added to the resulting semi-liquid mass. After being allowed to cool, it is broken into small pieces and mixed with glass or blast-furnace glass slag. The entire mixture is then subjected to a pressure of 200 atmospheres and reduced to whatever form or shape is desired. Its specific gravity is 2.2. Its crushing strength is 143 kilograms to the square centimeter. Its durability is considered to be about one-half of Swedish granite. It makes a pavement easily cleaned, and is said not to be slippery.

In 1898 an experimental pavement was laid in Lyons, France. It was made of blocks of devitrified glass. The blocks were eight inches square, each one being cut on top into sixteen smaller squares, so that the finished pavement looks very much like a huge checker-board.

The treatment consists in heating broken glass to a temperature of 1250° and compressing it into moulds by hydraulic force. The physical transformation of the glass is due to devitrification under the Garchy process. This action, however, is more apparent than real, as a chemical analysis shows that after devitrification the glass has the same composition as before. It possesses all intrinsic qualities of glass except transparency. It will also resist crushing, and heavy frosts, very much better than before treated.

In a pavement it is said to have greater resistance than stone, is a poor conductor of heat, so that ice will not readily form upon it, it is easily cleaned, and is sanitary. It is considered to be more durable than stone and just as cheap.

During the last few years pavements have been laid in some cities in the East of the so-called Scoria blocks. These blocks are composed of iron slag, the same being poured into molds while hot and allowed to cool gradually. These blocks are 8 inches

long, $3\frac{1}{2}$ inches wide and 4 inches deep. The blocks have bevelled edges so as to afford a foothold for horses, as the blocks themselves are smooth. The blocks are laid in the same manner as granite blocks, with a bituminous or a cement grout filler. The blocks are imported, and the pavement complete costs in New York a little less than granite. It has not come into very general use.

In New Orleans roadways of streets have been improved with shells. Oyster-shells are first spread over the roadway to a depth sufficient to give 6 inches when consolidated and then thoroughly rolled. Upon this another 6-inch layer of lake shells is placed and also rolled. This gives a nice, smooth, pleasing surface for light driving, but of course would not stand heavy traffic.

Another form of improvement is made of chert. Chert is a sort of disintegrated granite common in some parts of the South and possessed of a cementing property, after having been wet and rolled, that makes a hard, smooth surface upon a street. In New Orleans the subgrade is first covered with 1×12-inch cypress planks. The material is then spread in a 6-inch layer, sprinkled and rolled. Other layers 3 inches in thickness are added till the required depth of material is obtained. This makes a cheap and good roadway. The object of the planks is to prevent the chert from being rolled into the soft soil, and its moist condition should prevent the decay of the wood.

In the early eighties an artificial pavement called the Pelletier block was used in Chicago. It consisted of any hard stone, crushed and thoroughly dried, and then mixed with ten per cent of iron slag or low-grade ore. It was then subjected to a thorough infusion of a chemical combination of oxide and chloride of iron which was intended to act as a perpetual binder, growing harder and firmer with age and exposure to the weather. These blocks were subjected to great pressure during manufacture, and were impervious to water. They were never very much used.

In Cairo, Egypt, an attempt was made to form a street surface by pouring hot asphalt over a bed of broken stones. But the results were not satisfactory.

Later another experiment was tried by making slabs of bituminous asphalt concrete by mixing natural liquid asphalt with or-

dinary broken stone, and then laying a pavement with the slabs. This was but a partial success.

Between Valencia and Grao in Spain there has been a stone-paved roadway for some years. About 1890 a trial was made of laying flat steel rails in the wheel-tracks. The rails are laid double in the natural soil with no special foundation. Where they join a slight indentation is made so that wheels will more readily keep the tracks. The rails are kept in gauge by steel cross-bars spaced at proper intervals.

After the tramway had been in use for seven years the average annual cost for repairs had been $380, while previously the stone pavements required on outlay of $5470 per annum, or a net saving for repairs of $5090 each year, or for the seven years a total of $35,630, while the entire cost of the iron track was only $28,518. The average traffic on the road was 3200 vehicles per day. A charge of $^8/_{10}$ of a cent is levied for each vehicle.

In 1875 experiments were made in Budapest with a view of making paving-blocks of ceramite. By 1878 they had been produced with a crushing strength of from 27,000 to 43,000 lbs. per square inch. They were then adopted as a paving material, being $4 \times 4 \times 8$ inches in size. The method of laying was to form the natural soil of the street into the desired shape and lay on it flatwise bricks $3\frac{1}{2} \times 4 \times 11\frac{1}{2}$ inches. The joints of this first course were filled with cement mortar. A cushion of sand 0.8 inch thick was spread over the entire surface and the ceramite blocks laid upon it. The blocks were laid with 0.4-inch joint filled with a composition of 1 part coal-tar, 1 part pitch, and from 15 to 20 parts of sand according to fineness. The blocks weighed 22 pounds each. No description of the method of manufacturing or material of these blocks could be obtained, but from their name they probably were burned brick of especially prepared clay.

The following is a description of a patented noiseless stone pavement: Granite blocks 5×3 inches are wrapped, except the upper surface, with waste fibre and an elastic bituminous compound, and the whole brought together while resting on a continuous pad of the same material. The pad is taken to the street and unrolled over the concrete. The blocks are set diagonally and by a power-

ful lever pressed firmly together. This was claimed to make a smooth, noiseless, and sanitary pavement.

In 1896 a space 9 × 9 feet was cut out of an asphalt pavement in Topeka, Kansas, and then paved up with blocks of compressed wood pulp six inches square and four inches deep. This was subjected to a wear of about 720 vehicles per day. At the end of two weeks the wear was perceptible, but was not very extensive till at the end of four months, when the blocks wore so rapidly that they had to be taken up. On account of the wear, the asphalt was so broken near them that the original space of 9 × 9 feet had become 11 × 16 feet which required repaving.

A few years ago a novel pavement was laid in Oakland, Cal. It was a combination of wood and asphalt. The base was the usual cement concrete 6 inches thick. Upon this foundation were laid redwood blocks 6 inches square and 4 inches deep. The blocks were submerged in a bath composed of 80 per cent of hard asphalt and 20 per cent of liquid flux for about five minutes. It was found that the time of immersion did not affect the penetration of the asphalt as much as the temperature of the bath, which was kept from 350° to 400° to get satisfactory results. Previous to the block-laying, the concrete was given a thin coating of liquid asphalt at a boiling temperature, although it is admitted that it is doubtful if its utility justified the expense. It was done as an extra precaution to keep as much moisture as possible from the wood.

The blocks were laid close at right angles to the street. The joints were then filled with a grouting material composed of 80 parts of hard and 20 parts of liquid asphalt and 30 parts of carbonate of lime, being first mixed with 15 parts of liquid asphalt. The grouting was applied at three different times, so that all the joints should be filled and the blocks covered with about $\frac{1}{8}$ inch of asphalt. A coating of sand about $\frac{1}{4}$ inch thick is then spread over the entire surface. This sand is gradually absorbed by the asphalt, which thus becomes hard and firm, leaving the wood coated with $\frac{1}{8}$ inch of what is very similar to bituminous rock.

The grout when cold is said to hold the blocks together with a strength of 200 pounds per square inch. The asphalt covering is supposed to be only a carpet to carry the load that is really sup-

ported by the blocks. Its durability will be according to the traffic, but under conditions in a city like Oakland it is expected to last two or three years, when it must be renewed. The cost of renewal is about $4\frac{1}{2}$ cents per square yard. No expansion joints were left, as it was supposed that all absorption of moisture had been prevented by the asphalt bath. With proper renewals of the covering this pavement is supposed to last almost indefinitely, as the asphalt treatment of the redwood should prevent decay except after a very long time.

The Jetley pavement of London is thus described: "Under this system the wood blocks are compressed and combined very powerfully together by machinery and in such a manner that no block can afterwards move, and it is brought ready made to the street which is to be laid, in slabs 4′ 6″ × 12″ wide, and when the roadway is completed it forms a homogeneous structure from curb to curb so powerful that no block can move and consequently will remain perfectly level."

The slabs are laid without concrete, and when worn rough are turned over, giving practically a new pavement. After three years' service a pavement of this character was said to have been as smooth as when first laid.

These examples show how varied have been the attempts to find the best methods of improving streets and roads. They cannot all be said to have been failures, nor, if they had, would they be without value. Mankind as a whole, and engineers in particular, should learn by mistakes of their fellows as well as by their successes.

The question as to what is the best material for street pavements, and the detailed methods in which it shall be laid, is by no means settled at the present time. Much experimental work is going on now, but much has been accomplished during the past twenty years. At that time Belgian-block pavement was the improved pavement, and it composed a large proportion of the paved area of New York City. During the last ten years it has nearly all been replaced by asphalt or granite blocks, although it was in good condition. It makes way for its betters.

In Philadelphia, in 1884, 535 miles or 93 per cent of the pave-

ments of the city were of cobblestone. Now the cobblestone has almost entirely disappeared from the streets, and in its place are found granite, asphalt, and vitrified brick.

While many materials are now being used in pavements, it is safe to say that stone, asphalt, and vitrified brick are the only materials that should be considered to-day for street-paving purposes.

American cities have not seemed in the past to have profited much by the customs of their fellows. During the past fifty years nearly all of them have laid their first street pavements. In nearly every instance the city officials have worked out the problem for themselves. In some respects it was a new problem in each place. The best material for New York was not necessarily the best for Omaha, nor does it follow that Omaha's selection would be right for cities still further west. Economic conditions must always be considered. A city, like an individual, must be guided to a certain extent by its financial condition. The cost of transportation probably affects a selection more than any other one condition. Cedar blocks were cheap at Chicago, Milwaukee, and Detroit on account of water transportation, and, although of short life, have been used in those and some other Western cities long after they had been given up in most places where they had been tried.

Stone has long been acknowledged as being the most economical material for Eastern cities that can be easily reached by water, but its cost makes it prohibitive to the large number of places in the Mississippi Valley. Local conditions must always be considered, so that it is not possible to lay down any fixed rule as to what material makes the best pavement. But by a careful study and understanding of what properties are necessary for a good pavement, and a thorough knowledge of the materials proposed, an engineer can determine what selection should be made under given conditions. Understand the principles first and apply them afterward.

An ideal pavement should be cheap, durable, easily cleaned, present little resistance to traffic, non-slippery, cheaply maintained, favorable to travel, and sanitary. Letting the perfect pave-

ment have a value of 100 by a study of these different properties, it is possible to assign to each its proportional value of the whole.

CHEAPNESS.—No matter how desirable, or how economical even, any material may be, its first cost is a question of importance in deciding upon its availability. If the property owners cannot pay for it, the question is settled at once. There is no chance for argument. A committee's recommendation is often rejected when its wisdom is not questioned, simply on account of the cost. When the best cannot be taken this phase is developed: with the money available how can the best results be obtained? A person presenting a new plan or a new material will first be asked as to its cost. And if it be expensive, his will be a hard task to have it receive a fair trial except at his own expense. Cheapness, therefore, has been given a value of 15.

DURABILITY.—This is also an economic property. Upon this depends ultimate cost, and in this connection must be considered with first cost. If a pavement be cheap, and pleasing even, it can never be a complete success if it has not durability. Americans expect any construction to care for itself largely. They are not given to economies in repairs.

Durability, too, is affected by so many varied conditions that it is discussed with difficulty. It is acted upon principally by traffic and the atmosphere. The effect of the former depends directly upon its quantity, and the latter upon the character of the material and the climate to which it is exposed. For instance, untreated wood will have only a certain life even if it sustain no traffic whatever, while stone or good brick would last practically forever under the same conditions. Asphalt also is somewhat affected by the air, but not to such an extent as untreated wood.

The influence of traffic is modified by five principal conditions, viz., width of roadway, character of pavement, presence or absence of street-car track, state of repairs, and how well the pavement is cleaned. Traffic has been measured in this country by counting the number of vehicles passing over a street in a given time, and so arrive at an approximate tonnage without regard to width. In

England efforts have been made to arrive at more definite results, and the tonnage per yard of width of roadway per day or year has been taken as the unit. This reduces it all to a common standard, so that the traffic in one city can be easily compared with that of another.

In 1885 a series of observations were made under the direction of Gen. F. V. Greene to determine the amount of traffic in several American cities. The figures represent the number of vehicles of all kinds passing between 7 A.M. and 7 P.M.

Broadway, New York	7,811
Broad Street, Philadelphia	6,031
Devonshire Street, Boston	5,362
Douglass Street, Omaha	4,752
Fifteenth Street, opp. Treasury, Washington	4,520
Clark Street, Chicago	4,389

For comparison the number of vehicles passing in twenty-four hours in some foreign cities are given:

PARIS.	
Rue de Rivoli	42,035
Avenue de l'Opéra	29,500
Rue Croix des Petit Champs	20,480
Rue St. Honoré	19,672
LONDON.	
King William Street	26,793
Gracechurch Street	15,585
Queen Victoria Street	16,531
Cheapside	15,206
SYDNEY, AUSTRALIA.	
George Street	11,960

Width of Roadway.—The distance between curbs affects traffic as it tends to scatter or congest it. The wider a pavement is the more even will be its wear. If several lines of travel can be maintained irregularly, the wear on the surface will be more uniform and a better service received from the pavement. When vehicles are restricted to direct lines of travel, the wheels move in practically the same place from day to day, and the result is a rough and uneven surface in a comparatively short space of time.

Character of Pavement.—By this is meant the detailed method by which any particular material is laid. Asphalt pavements have been standardized, slight variations sometimes being made to meet special traffic conditions. But with stone, brick, and wood it is very different. Foundations vary for all, and the joint filling of each is what the experience or inclination of the particular engineer may suggest. Wood of one variety is used in one locality, and a different kind in another. It is treated chemically in one city, and laid in its natural condition in others, so that the word "wood" alone means very little as to the exact character of the pavement.

Presence or Absence of a Street-car Track.—A car-track has a great bearing on the action of traffic. On a rough, poorly paved street where the cars run at long intervals, vehicles naturally make use of the track, thus relieving the pavement from a large amount of its natural wear. On the other hand, on a well-paved street where cars run frequently, the traffic is confined to the space between the tracks and the curb, with all the evils of restricted travel.

In 1911 it cost $6\frac{5}{10}$ cents per square yard to keep in repair the asphalt pavement on street car streets in the Borough of Brooklyn, New York City, and $2\frac{9}{10}$ cents on streets where there were no car tracks.

In the Report of the Department of Public Works of the City of Buffalo for the year ending June 30, 1910, it is said that the presence of street-car tracks in a street reduces the life of the pavement about two years.

State of Repair.—This is of vital importance to a street pavement. If holes, depressions, ruts, or any defect in the surface are allowed to remain for any length of time, the material is displaced and consequently is worn abnormally. This fact is not fully appreciated by most city officials, but should they watch the effect of travel upon granite blocks loosely paved in a trench, they would soon be convinced. This is especially true of such materials as asphalt or broken stone.

Cleanliness.—The effect of street refuse on a pavement varies with its character. An imperishable material is benefited by having a cushion of detritus upon it. It serves as a carpet to protect the pavement, which when the cushion is heavy enough becomes the foundation only. This fact will often explain why certain materials are seemingly so much more durable in a small city than

in a large one. A poor brick pavement, for instance, will often give good results in a small place where the pavements are cleaned only at long intervals, when it would rapidly fail if kept clean under the same traffic.

This will not hold good, however, with wood or asphalt streets. Any street débris collects and retains moisture which hastens the action of disintegration and decay in any perishable material.

At one of the meetings of the National Brick Manufacturers' Association one member asked if city streets were not kept too clean; if brick pavements would not last longer and be less noisy if they were allowed to become more dirty. Although answered in the affirmative, he was told that in these times city streets would be kept clean despite the effect upon the material of the pavement.

All of the above conditions modify the action of traffic and thus affect the durability of any material. This property of durability has been considered to have a value of 21.

Easiness of Cleaning.—The experience of New York, Washington, Buffalo, and other large cities in cleaning streets has demonstrated to citizens and taxpayers that it is not only feasible but very desirable to have pavements kept free from natural street detritus. It has been shown so conclusively that it is an accepted fact that it is not alone desirable, but that it is absolutely necessary. The expense of street-cleaning is very great, and any device or any street-construction that will reduce it will be gladly welcomed by city officials.

The appropriation for the Street Cleaning Department of New York City for 1912 was $7,421,698. The benefit of smooth pavements to this department will be appreciated from a statement made in 1896 by Col. Geo. E. Waring, Jr., then Street Cleaning Commissioner of New York City. At a meeting of the American Society of Civil Engineers he said that if all the streets of New York were paved with asphalt where the grades would permit, and the street-car tracks constructed with grooved rails, the cost of sweeping the entire city would be reduced from $1,200,000 per annum to $700,000. That is, there would be a saving annually of $500,000, which capitalized at 4 per cent would amount to $12,500,000 in a city that then had a pavement mileage of 431 miles, of which

94 were paved with asphalt. A value of 15 is given to easiness of cleaning.

RESISTANCE TO TRAFFIC.—This is an important item. One of the chief provinces of a pavement is to reduce this, and consequently any pavement that can bring it to a minimum is of special value. A mechanical device that would reduce the friction of a machine 25 or 50 per cent would be recognized at once as of great benefit. There is fully this difference in the various pavements, and this must be recognized and considered before deciding on any particular material. If one horse can draw on one pavement a load that would require two horses on another, the truckman at once sees the importance of a proper selection. Light resistance to traffic is valued at 15.

NON-SLIPPERINESS.—The slipperiness of a pavement depends upon its material and also upon its condition. The efficiency of a draft-horse varies with his foothold. If that be good, he can use his entire strength to draw his load; while if he be in constant danger of slipping and falling, he will accomplish very little. Instead of using all his power to overcome the resistance of the load, he uses it only to the slipping-point.

The condition of the weather and the climate modify this. An illustration of this is shown in a case where observations were being taken on several asphalt-paved streets in extreme winter weather. On the first day the hourly traffic was 225 tons between 11 and 12 o'clock, reaching 270 tons between 3 and 4 o'clock P.M. On the following day the traffic between 11 and 12 o'clock was 305 tons. About 2 o'clock snow began to fall, the mercury being about zero, making the pavement so slippery that the traffic was reduced to 40 tons between 3 and 4 o'clock, and the street was soon practically deserted. The same results were obtained on all other streets where observations were being taken. Non-slipperiness is assigned a value of 7.

In the light of the above this value may seem small, but it must be remembered that these special conditions seldom arise, and, while effective while they do exist, do not have as much influence as a smaller force acting continually.

EASE OF MAINTENANCE.—Maintenance is closely allied to first cost, and many engineers think that they should be considered

together. To a certain extent this is true, but mainly when the question of ultimate economy is being considered. The cost of repairs liable to be incurred to keep a pavement in good condition should be ascertained as accurately as possible in advance. No material can be intelligently adopted without it. What often seems a wise and sound selection is ruled out simply by the cost of repairs. All works constructed by man require constant attention, and a pavement is no exception to the general rule. But that material which needs the least and allows that to be done at the least expense, as well as inconvenience to the public, is the best, other things being equal. This property has been ranked at 10.

FAVORABLENESS TO TRAVEL.—By this is meant the ease and comfort that are enjoyed in driving over a smooth pavement, and also the decrease in the wear and tear of vehicles, as compared with one that is rough and uneven. It is difficult to estimate this exactly, but some approximations have been made.

The French engineers say that 50 per cent is saved in the wear and tear by having smooth pavements.

A London engineer in 1827 stated that good pavements in London, Westminster, and Southwark would save £140,000 per annum in wear and tear of vehicles and horses. The area included in the above was 3818 acres, but it must be remembered that the streets of London at that time were in a specially bad condition.

In a paper read before the Institution of Civil Engineers in 1871 Mr. Geo. F. Deacon said: "Since the new Liverpool pavements have been constructed without giving credit for the great reduction of wear and tear of horses and vehicles, there was a saving of £10,000 per year for every mile of the new pavements now laid on the dock line of the streets of Liverpool."

Smooth pavements are a luxury also. It is a pleasure to drive on some streets, and positively painful on others. Wheeled vehicles are equipped with pneumatic tires to make the pleasure as great as possible, but much can be done to aid it in the pavements itself. With the introduction of the automobile, and the possibilities of its extension, this property of favorableness to travel is bound to receive more attention from year to year. At the present time it is valued at 5.

SANITARINESS.—Another important requisite of a pavement is that it should be sanitary. A great amount of decaying organic matter, house-garbage, horse-droppings, and various kinds of filth must be deposited in the streets despite the utmost care of citizens and public officials. Any pavement that will allow any of this to collect in joints, or soak down to the surface to the underlying soil, out of the reach of street-cleaners, must be deleterious to the public health. Any material that will readily absorb moisture and give it forth in dry seasons must be considered as unsanitary. Therefore a pavement that has a smooth surface, is impervious to water, and is not made up of organic matter subject to decay will be desirable from the standpoint of the sanitarian.

Noise, too is an important factor. A noisy material prevents sleep, rasps on the nerves of both the sick and the well, and prevents conversation on the street. This is considered of great importance in large cities where in selecting the material for repaving any street special care is taken that noiseless pavements be laid in front of churches, schools and hospitals. Sanitariness is rated at 13.

Having now studied somewhat in detail the characteristics of a pavement and obtained a value for each, it will be in order to take up the different paving materials themselves, and by careful examination determine how much of each total is to be apportioned to each according as it approaches perfection in each property.

The pavements that will be considered are: oblong granite blocks laid on 6 inches of cement concrete with tar and gravel and grout joints; sheet asphalt, wearing surface 2 inches thick and binder 1 inch, on 6 inches of concrete; vitrified brick, also laid on a 6-inch concrete base with joints filled with pitch or Portland cement; treated wood blocks on 6 inches of concrete; and bitulithic on the same foundation.

First Cost.—This of course will vary in every locality, and a different apportionment must be made for every change in price. The following figures are based upon average prices for New York City in 1911 (all per square yard complete):

Granite	$3.50
Wood	3.50
Asphalt	2.00
* Brick	2.25
* Bitulithic	2.35

Assuming their values to be inversely as their cost, granite A has 2, granite B 4, asphalt 4, brick 3, Belgian 5.

Durability.—This, as has already been seen, varies greatly according to many conditions, so that any conclusion must be general.

It must be remembered, also, that there are two ends to all pavements, a physical and an economical end. The former comes when the material is so worn out that it cannot be repaired and must be relaid; the latter when the cost of repairs is so great that it will be economy in the end to relay at once. The former test will generally be applied to stone, brick, or any block pavement, and the latter to asphalt or macadam. When a pavement is made of moderately sized parts of practically the same character, the wear on the parts is about the same amount, and to repair it requires taking up the old material and replacing it with new rather than adding to the material on the street. But when a pavement is made up of parts so small that they must be consolidated into a continuous whole it is different.

The physical end of a pavement can be determined by observation as the blocks wear out.

Asphalt and bitulithic wear away by degrees, and can be added to in whatever quantity it may be desired and its physical life thus prolonged indefinitely. The economic test must than be applied to ascertain when the repairs must be stopped and a new pavement laid. Assume a street to be paved, and the expense of keeping it in repair is so great that the question arises, shall it be repaved or the repairs continued?

* Estimated.

Let N = life of proposed pavement;
C = cost per square yard;
I = rate of interest;
R = estimated total cost of repairs if distributed over entire life;
A = sinking fund to be paid each year to equal C at end of N years.

Then

$$A+CI+\frac{R}{N}=\text{annual expense of new pavement.}$$

Take, for instance, an asphalt pavement, and let $N=18$ years, $C=2.00$, $I=4$, and $R=0.72$. Then A will equal .0702 and the equation becomes \$0.0702+.08+.04=\$0.1902, or if the street be repaved, it will cost annually \$0.19 till it is renewed. Consequently if the life of asphalt be correctly assumed at 18 years, it should not be repaved until the annual cost approaches \$0.19 per square yard. Assuming the life to be 20 instead of 15 years and applying the formula as before, the annual cost will be reduced to \$0.1872 per yard.

The author believes that this is the scientific, the engineering, and the only true way of telling when an asphalt pavement should be relaid. The only element to modify this principle is the inconvenience traffic and property owners on the street are put to while repairs are being made. The determination of this must be made in each case. But the principle of the formula is correct, and when cities have had a larger experience with asphalt pavements, and repair accounts are kept in a more intelligent way, there will be no difficulty in determining the variables.

A series of experiments were made in St. Louis in 1880 to determine the resistance to abrasion of several kinds of paving material.

Strips of pavement 22 inches wide were laid of fire-brick, asphalt blocks, granite and limestone blocks. A traffic standard of 50 tons per day per foot of width of roadway was adopted, and a two-wheeled cart with 2½-inch tires loaded 800 lbs. per inch was rolled over the different strips long enough to equal a traffic of 8½ years. The fire-brick lost 9 per cent in weight and a depth of ¾ inch, with about one-half broken. Asphalt blocks lost 14 per

cent, limestone blocks 10 per cent, while the wear on the granite was hardly appreciable.

The officials of different European cities give the average life of the different materials as follows:

TABLE No. 42.

	Granite.	Asphalt, Years.	Wood.
Glasgow	50	....	6
Edinburgh	30	12 to 15	Redwood 8 Australian 15
Liverpool	30	12	15 to 18
London	....	....	5 to 8 for Baltic deal Australian 12
Paris	30	15	8

From the above and data collected from American cities the estimated life of granite is 25 years, treated wood 20 years, brick 15 years, asphalt 18 years, and bitulithic 18 years.

These estimates give to granite a value of 21, wood 16, brick 12, asphalt 15, and bitulithic 15.

Easiness of Cleaning.—Some figures have already been given showing the benefits of smooth pavements when they are to be cleaned. How necessary this is can be recognized from a statement made by a committee of the Society of Arts, London, in 1875, to the effect that at that time it was estimated that 1000 tons of horse-manure was being dropped daily upon the streets of London. This had to be taken up and removed to avoid being incorporated into the human system through the respiratory organs. Other refuse of all kinds collects upon our streets, and the pavement that uniformly presents a hard, smooth, and even pavement is cleaned at much less expense than one that is rough and uneven. In accordance with this principle, then, granite has a value of 10, wood 14, asphalt 14, brick 15, and bitulithic 14.

Light Resistance to Traffic.—Many experiments have been made to determine the force necessary to draw a given load over roads and pavements of different character. The most of them were made, however, a good many years ago, those of Morin having been carried

out in 1843, and those of Macneil in 1838. Since that time changes have occurred in the same kind of pavement, one of stone block, for instance, being very different from that of fifty years ago, so that the results arrived at then may not be absolutely correct to-day, but relatively they should not be far from right. Then, too, the actual condition of the pavement must vary results considerably. Differences of temperature would change results on asphalt, the traction being appreciably greater in the summer, when the pavement is soft, than in the winter. It is to be regretted that more modern experiments have not been undertaken on any extended scale with modern appliances to settle this question.

At the Atlanta Exposition in 1895 the Department of Agriculture experimented to some extent with some roads and pavements that were available at that time and place. Table No. 43 gives the results reached.

TABLE No. 43.

	Pounds.
Loose sand (experimental)	320
Best gravel, park road	51
Best clay	98
Best macadam	38
Poor block pavement	42
Cobblestone	54
Poor asphalt	26

Table No. 44 gives the force in pounds per ton required to draw a load over different surfaces as given by Prof. Haupt in a paper published in *Journal of the Franklin Institute* in December, 1889.

In 1893 the Studebaker Brothers of South Bend, Ind., made some experiments on this subject, and a portion of their results is given in Table No. 45. The figures represent force in pounds per ton.

These results would seem to indicate that a load is not hauled much more easily on wide tires over ordinary roads than on narrow, and that on stone pavements the narrow tires actually require less traction. This last is probably due from the fact that a stone pavement must necessarily be more or less rough, and that a wide tire will be apt to pass over more bunches than a narrow one, and as the load must be simply lifted over the bunch in either case,

TABLE No. 44.

Character of Roadway.	Pounds per Ton.
Sand	400
Gravel	200
Ordinary earth	200
Dry clay	100 to 66
Good cobble	133 to 66
Ordinary cobble	250
Ordinary macadam	80 to 57
French macadam	40
Stone block	80
Belgian block	50
Belgian block, well laid	33
Asphalt	15
Smooth granite trams	12
Iron trams	10

TABLE No. 45.

	Diameter of wheels 3 ft. 8 in. and 4 ft. 6 in. 4-inch Tire.		1½-inch Tire.	
	To Start.	To Move.	To Start.	To Move.
Block pavement	161	46	142	35
Good sand roads	323	127	343	180
Good gravel roads	276	81	308	83
Muddy roads	369	254	422	237

more traction will be required with wide tires on a hard surface that is not smooth.

The committee of the Society of Arts previously referred to experimented on the streets of London in 1875 to ascertain the force required to draw loads over different roadways at varying rates of speed. Table No. 46 gives results.

The report added that the asphalt experimented on was not in good condition, and for that reason the force shown for asphalt was undoubtedly higher than it otherwise would have been. These figures, however, are valuable as they give the effect caused on the draft of increased speed.

Table No. 47 is made up from the results of different experimenters, the figures representing the force in pounds to draw one ton at a speed of approximately 3 miles per hour.

From all these figures it is considered, taking into consideration the varying conditions under which all tests were made, as well as the improved character of pavements at present, and remembering

TABLE No. 46.

Character of Pavement.	Speed in Miles per Hour.	Force in Pounds to move One Ton.
Gravelly macadam	6.945	44
Do.	3.45	39.8
Granite macadam side of tramway	5.15	24.7
	3.196	14.6
Do.	2.557	16.5
Granite blocks freshly laid	4.239	91.3
	2.775	84.4
Asphalt	5.025	30.8
Do.	3.56	24.2
Do.	5.687	29.3
Wood	3.932	41.1
Do.	3.278	35.6
Do.	3.827	34.8
Good macadam	6.65	37.9

TABLE No. 47.

Character of Roadway.	Pounds.	Authority.
Ordinary dirt road	200	Bevan
Hard gravel	66⅔	Bevan
" "	66⅔	Minard.
" "	51	U. S. Govt.
Bad macadam	143	Gordon
Old macadam	100	Navier
Good macadam, wet	36 to 66⅔	Morin
Best macadam	33⅓ to 43⅓	Gordon
" "	28⅔ to 46⅓	Morin
" "	44⅘	Rumford
" "	38	U. S. Govt.
Ordinary cobblestone	125	Kossack
Good cobblestone	62½	Kossack
Cobblestone	54	U. S. Govt.
Belgian block	47½	Navier
" "	23 to 44⅘	Morin
" "	31	U. S. Govt.
" " good	33⅓	Rumford
Ordinary stone block	80	Minard
" " "	33	"
Good stone block	40	Rumford
London stone block	32	Gordon
Poor stone block	42	U. S. Govt.
Asphalt	15	Gordon
" poor	26	U. S. Govt.
"	15	Haupt
"	24	London Experiment

that the resistance to traffic increases very much on the bituminous pavements in hot weather, that the following values should be assigned: granite 13, wood 14, brick 15, asphalt 11, and bitulithic 12.

The general opinion among engineers is that the tractive force varies inversely as the diameter of the wheels, but some say inversely as the square root of the diameter. Mr. W. Hewitt in a paper before the Surveyors' Institution of England says: "From experiments made with Eastren and Anderson's horse-dynamometer at the Royal Agricultural Show, 1874, a slightly greater ratio than inversely as the diameter was given, and I am inclined to think that inversely as the diameter is the more correct view of the two."

Slipperiness.—A great many conditions affect this property: conditions of the street, temperature, whether wet, damp, or dry, etc.

Mr. Wm. Haywood, Engineer to the Sewer Commissions of London, made some very extended observations in the London streets in 1873 to determine the liability of horses slipping on asphalt, granite, and wood pavements.

The asphalt observed was the ordinary rock asphalt of that time, 2½ inches thick on a 9-inch concrete base, with the surface in good condition. The grades varied from 1 in 58 to 1 in 550.

The granite pavement consisted of Aberdeen blocks 3 inches wide, 9 inches deep, and from 9 to 15 inches long, laid stone to stone, the joints being filled with stone-lime grout. The pavement as a whole was not in good condition. The grade varied from 1 in 30 to 1 in 1000.

Two wood pavements were experimented with. One was formed of fir blocks 3 inches wide, 5 inches deep, and 9 inches long. The blocks were laid touching each other at the ends, but crosswise of the street; the joints were ¾ inch wide, filled in with thin gravel and grouted in with a bituminous composition. The other consisted of beech blocks 3½ inches wide, 4½ inches deep, and 6 inches long, with ¼-inch joints at side and ends, filled in with cement grout. The grades varied from 1 in 30 to 1 in 260.

The asphalt was sprinkled slightly with sand, and the wood four times with gravel. The wood and granite were watered to lay

the dust, but the asphalt was not treated. All the pavements were kept as clean as their nature and respective surfaces admitted with the usual amount of labor. All observations were taken between 8 A.M. and 9 P.M.

The mean number of horses passing daily in March and April was:

Asphalt	Cheapside	12,366
	Poultry	10,920
Granite	King William Street	8,555
	Cannon Street	5,850
Wood	King William Street	21,162
	Gracechurch Street	11,484

Table No. 48 shows the total number of horses that fell on the different streets during the fifty days on which observations were taken, as well as the daily mean.

TABLE NO. 48.

Character of Pavement.	Street.	Distance Travelled in Miles.	Total Number of Accidents	Miles Travelled for Each Accident.	Daily Mean.
Asphalt	Cheapside	172,783	932	185	18.64
	Poultry	31.022	134	231	2.86
Granite	King William Street	54 688	429	127	8 58
	Cannon Street	40,884	290	140	5.80
Fir-wood	King William Street Gracechurch Street	169,69C	380	446	7.60
Beech-wood	Gracechurch Street	9,461	162	58	3.24
		478,523	2327	......	46.72

The mean being: Asphalt 191 miles travelled for each accident.
Granite 132 " " " " "
Wood 330 " " " " "

"Accidents" in this connection mean falls on knees, falls on haunches, and complete falls. No account was taken of horses slipping simply. During the last thirty-two days record of these different occurrences was kept, and the percentage of each is shown in Table No. 49.

TABLE NO. 49.

	On Knees.	On Haunches.	Complete.
Asphalt	32.04	24.48	43.48
Granite	40.39	7.56	46.05
Wood	84.97	3.07	11.96

Table No. 50 shows the distance in miles horses travelled without accident under three different conditions of surface moisture.

TABLE No. 50.

Pavement.	Dry.	Damp.	Wet.
Granite	78	168	537
Asphalt	223	125	192
Wood	646	193	432

Mr. Haywood thinks that the accidents on the beech pavements should be eliminated, as they were not typical pavements, when the true order of slipperiness would be:

	Miles.
Granite	132
Asphalt	191
Wood	446

It must be borne in mind that the asphalt experimented on was the European natural rock asphalt, which is admittedly much more slippery than American asphalt.

In summing up Mr. Haywood says:

"Taking the whole group of conditions into account, the asphalt was the most advantageously placed, the wood was the next so, and the granite was the worst placed.

On the average of the whole fifty days' observations, the granite was found to be the most slippery, the asphalt the next so, and the wood the least.

Separating the accidents under three conditions of surface as regards moisture, it appears that asphalt was most slippery when merely damp, and safest when dry; that granite was most slippery when dry, and safest when wet; that wood was most slippery when damp, and safest when dry."

In 1885 Capt. F. V. Greene had a series of observations made in ten of the principal cities of the United States to determine the relative slipperiness of the same kinds of pavements as laid in this country. From his results he decided that on pavements in American cities a horse would travel 272 miles on wood, 413 on granite, and 583 on asphalt without an accident. His accidents were divided also into falls upon the knees, falls upon the haunches, and complete falls. On a rough pavement falls upon the knees should not be wholly charged to slipperiness, as a great many must

be caused by stumbling. Capt. Greene found that, of a total of 84 falls, 68 were upon the knees. Assuming that one-half of the latter were stumbles only, the deduction would be that a horse would travel 698 miles on granite without an accident due to slipperiness. These results of course are general.

From these and personal observations, granite is given a value of 7, wood 4, asphalt 5, brick 6, and bitulithic 6.

Maintenance.—The cost of repairs to pavements varies greatly in different cities. It is governed principally by the character of the material, nature and amount of traffic, and the condition in which the streets are kept. No satisfactory records are available on this subject. Few cities keep their accounts in such a manner that it is possible to tell how much money has been spent on different kinds of pavements. Then, too, officials have different standards of good repair. One city will not tolerate what is considered very good in another. Granite when properly laid requires but little attention for some years, and then by relaying the blocks the pavement may be made good for a number of years.

The Surveyor of the Greenwich, Eng., District Board of Works said in 1891 that a granite-cube paved road cost 12 cents per yard per annum for repairs.

In Birmingham, Eng., granite lasts seven years without any cost, for the next seven years from 6 to 14 cents per yard per year, after which in the heaviest-traffic streets it would require relaying at a cost of about 73 cents per yard, when it would last as above another fourteen years, and even then the best of the stone could be redressed and used on light-traffic streets, and the remainder used for macadam. Wood costs nothing for the first year, then from 15 to 18 cents per yard per year for twenty years after, according to location.

In Dresden macadam cost for repairs in 1889 4½ cents per yard.

In London in 1884 macadam cost on Parliament Street 70 cents, on Whitehall Street 71 cents, and on Victoria Street 50 cents per yard for repairs. On five principal London streets granite averaged 10 cents per yard per year.

Contrary to the general belief, cobblestone does not stand well under heavy traffic. There is not sufficient stability in the stones

to stand the blows they are subjected to, and the results is that they are knocked out of place. Portions of several cobble-paved streets in Brooklyn, N. Y., which made a connection between granite pavements over which a large amount of traffic was carried, cost 19½ cents per yard per year for repairs. The cost of repairs for nine years was enough to repave them with granite blocks on a sand base.

The subject of repairs of asphalt will be taken up in another chapter.

The values assigned are: granite 10, wood 8, asphalt 6, brick 6, and bitulithic 6.

Favorableness to Travel.—This is a difficult property to reduce to a cash basis. Some engineers say that the amount of noise made by driving a wagon over different kinds of pavements shows the relative amount of damage caused to the wagon. While this may seem a strange standard, it is a logical one, as it is well known that the smoother the pavement the less noisy it is.

In response to an inquiry as to the difference in wear and tear to delivery-wagons and horses when the asphalt pavements of Brooklyn, N. Y., were increased from 15 to 65 miles in a total pavement mileage of about 500, two of the largest dry-goods firms said:

"We desire to say that there is a very appreciable difference in our wear and tear account since the increase of asphalt pavements. No more damage has been done to our horses, and of course it goes without saying that the saving to wagons must be very great."

"We beg to state that the effect of the pavements of this Borough has been of such a character as to save us considerable wear and tear on our wagons, and lameness to our horses."

In 1896 the Poughkeepsie Cab and Transfer Co. said in answer to an inquiry: "We would say that our repair bill for 1895 was 50 per cent less than in 1894, and our shoeing bill 42 per cent less in 1895 than in 1894. We attribute this in a great measure to the introduction of smooth pavements in our city." Poughkeepsie at that time had about 28,000 square yards of asphalt block pavement.

In 1889 the following two questions were put to the omnibus-drivers of London:

1st. Which do you consider the best form of roadway to drive over?

2d. Which the worst?

The answers were:

1st. 750 wood; 219 macadam; 197 granite; 51 asphalt.

2d. 122 wood; 1 macadam; 13 granite; 1045 asphalt.

It must be remembered, however, that the asphalt pavement is that laid of natural rock and probably subjected to as bad a climate for slipperiness as that of any city in the world.

The condition in which a pavement is kept affects different pavements differently. An editorial note in *Engineering* in 1876 says: "Cornhill was blocked for nearly an hour through the falling of horses, and the scenes in Cheapside, Eastcheap, Mowgate Street, are simply disgraceful, not from the fault of the paving of the roadway, but simply because it is not kept clean." This referred to asphalt. The values given to different pavements are: granite 2, wood 5, asphalt 4, brick 3, and bitulithic 4.

Sanitariness.—There is a great difference in the sanitary value of the pavements in question. The committee of the Society of Arts of London elsewhere referred to made the following statement on this point:

"In urban districts which have been well drained with proper self-cleansing sewers and freed from emanations from them, fever has been found to lurk in those quarters where the surface paving and surface cleaning are bad. On the other hand, the extension of impermeable pavements alone, other conditions as to drainage, etc., remaining the same, has been attended with a marked reduction of malarious disease."

At the time of the cholera in London in 1848, it being impossible to clean the cobble-paved streets, the Board of Health covered the surface with 3 inches of clean earth.

"As a sanitary rule perfect impermeability of street covering is of primary importance."

These principles are unquestionably correct. And consequently

asphalt with its smooth, impermeable surface ranks very high. Granite A and brick also resist moisture. But they are more noisy, and noise must be considered under this head. Noisy streets affect one's nervous system, and a noisy pavement is poorly adapted for streets near hospitals, schools, and similar buildings, whatever may be their qualities in other respects. Granite B and Belgian have joints filled with sand which is partially swept out and replaced with street refuse of all kinds. Decaying as it must, it is always offensive and unhealthy. The sand joints also allow moisture to accumulate, which is a source of disease. A cobblestone pavement can never be kept clean. To make it so it would be necessary to remove all the supporting material between the stones, and the result would be a collection of loose rocks.

Macadam is always dusty if not thoroughly and frequently sprinkled. It absorbs and gives off moisture readily and should not be considered as a street pavement, although it ranks high in some respects.

In the old city of New York the number of deaths in 1892 was 44,329; in 1893, 44,486; in 1894, 41,175; in 1895, 43,420; in 1896, 41,622; in 1897, 38,877; in 1898, 40,240; and in 1899, 39,822,—showing an absolute decrease of 4507 despite the large increase in population. This is a remarkable record. It can be accounted for in part by increased sanitary measures in general, and largely by the laying of asphalt pavements on the east side in the tenement district, where the population is denser per acre than in any other city of the world. The streets have been kept clean and have served largely as recreation-grounds of the people in the evenings and on Sundays. As a sanitary pavement, then, granite receives 9, wood 13, asphalt 12, brick 10, and bitulithic 12.

Having now discussed each property which is possessed by a pavement and assigned to each its proper percentage value, as well as considered each pavement in relation to these different values, it will be possible to construct a table that will show in detail how each material stands relatively to any other, and also what proportion of the properties of a perfect pavement is possessed by each pavement under consideration.

TABLE No. 51.

	Percentage.	Granite.	Wood.	Brick.	Asphalt.	Bitulithic.
Cheapness	14	8	8	13	14	12
Durability	21	21	16	12	15	15
Easiness of cleaning	15	10	14	15	14	14
Light resistance to traffic	15	13	14	15	11	12
Non-slipperness	7	7	4	6	5	6
Ease of maintenance	10	10	8	6	6	6
Favorableness to travel	5	2	5	3	4	4
Sanitariness	13	9	13	10	12	12
Total	100	80	82	80	81	81
Less cheapness	....	72	74	67	67	69

It may be said that cheapness is not a physical characteristic of a pavement and that in discussing the characteristics of pavements that item should be omitted. This is true to a certain extent, but as in all cities costs must be taken into consideration it has been included in the table. Eliminating this item, however, and making wood, which has the highest value, the standard at 100, the values of the other pavements will be:

Granite	97
Bitulithic	93
Brick	91
Asphalt	91

It must be understood, of course, that the table is a general one; that much of it is based on the personal judgment of the author, and it will vary in different localities, even if the conclusions are agreed to. The author understands that in estimating the life of bitulithic and treated wood pavements there is much uncertainty, as neither of these materials has been in use long enough to make a positive determination. This is also true of the cost of repairs of all pavements, as the records of the different cities as to costs and the work itself have been of such a character that these records are of little value. The life of the known pavements, too, varies according to conditions. For instance, a granite-block pavement could be laid upon a residence street

where the traffic was slight and where it would last almost indefinitely. On the other hand an asphalt pavement could be laid on a street where the traffic was heavy and where its life would be measured by months almost rather than by years.

In the paper of M. P. Tur, elsewhere referred to, it is stated that on certain streets of Paris an asphaltic pavement will not last more than two years, while elsewhere its life may reach 13 or 14 years. In the table, however, it is assumed that each pavement will be laid upon streets for which it is adapted and that traffic will be the average for such streets.

It may be felt too that the life of brick pavement at 15 years is too short. This is undoubtedly true if the pavement is used in the smaller cities, but is considered to be reasonable in such cities as Philadelphia and St. Louis, where it has been used in large quantities. In the many cities of the Central West it would undoubtedly have a life of from 20 to 25 years, and possibly in some instances even more.

The working of the table can be illustrated in several ways.

Assume, for instance, a street over which the traffic must be heavy and continuous. Ultimate cost is of great importance. It overrules first cost. Light resistance to traffic and foothold for horses are ruling elements, so that a given power may move its maximum load. The items first to be studied are, then: Durability, maintenance, traction, and the non-slippery property. Consulting the table and combining the values for these items, granite has a value of 51, wood 42, asphalt 37, brick 39, and bitulithic 39.

Granite has such a decided advantage over this that further study is not necessary to come to a proper decision. But when the figures are as close as the last three, ranging from 37 to 39, a careful examination of the remaining properties would be required. In this particular instance granite ranks so high in the totals, and so far ahead in the special requisites, that it would seem that no mistake could be made in selecting it for the material to be used.

Consider next a residential street, built up with homes whose owners have means sufficient to afford the best of anything they desire, and, while not wishing to be extravagant, do want and ex-

pect the best pavement that can be laid without regard to expense.

This is an entirely different proposition. Cost, durability, and maintenance, so important before, can be left out of consideration altogether. Easiness of cleaning, non-slipperiness, favorableness to travel, and sanitariness are the governing characteristics. Working as before, granite has 28, wood 36, asphalt 35, brick 34, and bitulithic 36.

In this instance wood and bitulithic have the same values, according to the table, but asphalt is very close, so that the special qualities of each one should be considered before making a final decision.

It may be said that duraility and maintenance are too hastily disposed of, and that by considering them the results would be changed. But this is the point of the selection. The property owners can afford the best. They would not carpet their parlors with hemp or matting because it would last longer than tapestry, nor furnish their dining-room table with crockery and pewter rather than with china and silver. The problem is to select the best material under existing conditions.

The above conclusions would generally hold good for the best retail streets.

Next consider a residence street with very light traffic, where the abutters wish a good but economical pavement, one that will be durable and as near the best as their financial condition will admit. This requires careful consideration. The destructive action of travel is almost wholly eliminated. Durability will be governed by the action of the elements. Every quality but slight resistance to traffic must be taken into account. This gives: granite 67, wood 68, asphalt 70, brick 65, and bitulithic 69. Asphalt leads bitulithic by one point. It is, however, a somewhat cheaper pavement, and as its characteristics are practically the same, and for the conditions specified a property owner would undoubtedly select it as his choice.

The above examples illustrate the workings of the table, showing how it is possible to analyze the conditions that may arise in any case, and how easy it is to arrive at an intelligent and logical result when a systematic investigation is undertaken.

An engineer who has under his charge the maintenance and renewal of a large amount of pavement will be governed by slightly different principles from those just laid down. He will have a certain sum of money from year to year to be used on this work, and it will be his duty to make the most of it. He is now endeavoring to benefit the entire city, not the residents of any one section, as the funds for this purpose are raised by taxation upon the city at large. He should be governed more by ultimate economy than first cost. He must take into consideration, too, the interruption to travel by too frequent repair on business streets. A material that might be figured out as economical, even if short-lived, by reason of its cheapness both of first cost and renewal, might require so much attention as to be an actual nuisance on a business thoroughfare. He should not only have a thorough knowledge of the characteristics of the different paving materials, but he should also know thoroughly the quality as well as the quantity of traffic on each street. The people of different cities speak of heavy traffic. This, however, is only a relative term, as what is heavy traffic for one city is not necessarily so for another. It can be readily understood, also, that it makes a difference whether the tires of the vehicles are rubber or steel, also at what rate the different vehicles move, as a swiftly moving vehicle, if it is heavily loaded, causes more wear and tear to a pavement that one moving at a slower rate.

Practically no cities of this country, and not many in foreign countries, have any census statistics of their streets that are of value, and until they have it is not possible to determine from a scientific standpoint the proper pavements for the different streets.

The official who decides on the material after the most careful investigation will often find that his decision is displeasing to many people. This often must be the case, as the wishes of the users of the street often conflict with the wishes of the people who do business on the street. The users of the street desire a pavement that is most conducive to ease of trucking, and, if that be satisfactory, care little for the noise or other inconvenience, while the people who do business on the street, or occupy residences thereon, wish a quiet pavement and are not so much

interested in its adaptability to traffic. He must make his decision after taking all things into consideration and stand by it, although it will not always prove satisfactory to all. The appropriation is generally inadequate for his work, and careful study is necessary to bring about the best results. The smaller the amount the more time should be spent in directing its expenditure. An eminent authority has said that if one has but five minutes in which to perform a difficult task, three minutes should be consumed in ascertaining how to do it.

The official who occupies such a position will find himself confronted with an interesting and ever-varying problem. Conditions are constantly changing, traffic is divided, and circumstances keep arising that require his faculties to be ever alert. But if he meet the question successfully, and ultimately arrive at the true solution, his satisfaction is as great, perhaps, as in any other branch of his profession.

In estimating the life of a certain material to be laid on any particular street, it must be remembered that when any one road is selected to be made into a thoroughfare, traffic will be immediately diverted to it and the wear of the pavement abnormally increased. Consequently the natural life of the material must not be judged by its wear on this particular street.

Taking now the costs and lives of the different pavements as herein deduced, the actual annual expense of each for a period as near fifty years as will be convenient for each material can be easily maintained and compared by the formula

$$A+CI+\frac{R}{N}=\text{annual expense.}$$

For granite: $C=\$3.50$;

$I=\ \ .04$;

$R=\ 2.00$—estimated cost of total repairs during life;

$A=\ \ .084$;

$N=25$ years.

Substituting in the equation,

$$\$0.084+.14+\frac{2.00}{25}=\$0.304 \text{ for first period.}$$

For the second period, assuming the value of the concrete to be \$0.70 per square yard, making the cost of relaying \$2.80 per yard, the annual expense is found as before to be \$0.2512, or for fifty years an average of \$0.2776.

For wood: $C=\$3.50$;
$I=\ .04$ as before;
$R=\ 1.00$ estimated cost of total repairs during life;
$A=\ 0.1176$;
$N=20$ years.

Substituting,

$$.1176+.14+\frac{1.00}{20}=0.3076 \text{ for first period;}$$

for second period 0.24604, and for fifty years an average of 0.2706.

For asphalt: $C=\$2.00$;
$I=\ .04$;
$R=\ 0.72$;
$A=\ .0714$;
$N=18$ years.

Substituting,

$$\$0.078+.08+\frac{72}{18}=0.198 \text{ for first period.}$$

For any subsequent period, assuming the cost of repaving to be \$1.25 per square yard, the expense will be \$0.13875 per yard, and for fifty-four years an average of \$0.1585.

For brick:

$$C = \$2.25;$$
$$I = .04;$$
$$R = .60;$$
$$A = .1123;$$
$$N = 15 \text{ years.}$$

Substituting,

$$0.1123 + .09 + .04 = 0.2423 \text{ for first period.}$$

For any subsequent period, assuming cost of repaving to be $1.55 per yard, the annual expense will be $0.1793, or an average for forty-five years of $0.20 per year.

For bitulithic:

$$C = \$2.25;$$
$$I = .04;$$
$$R = .72;$$
$$A = .09165.$$

Substituting,

$$.09165 + .094 + .04 = 0.22565 \text{ for first period.}$$

For any subsequent period, the cost will be 0.17035, or an average of 0.19 for fifty-four years.

Table No. 52 shows the above results condensed.

TABLE No. 52.

Material.	First Cost per Square Yard.	Expense per Yard for First Period.	Expense per Yard for 50 Years.
Granite	$3.50	$0.304	$0.2726
Wood	3.50	0.3076	0.2706
Asphalt	2.00	0.198	0.1585 *
Brick	2.25	0.2423	0.20 †
Bitulithic	2.35	0.22565	0.19 *

* 54 years. † 45 years.

In 1898 the city of Minneapolis, Minn., awarded a contract for asphalt pavements for $2.15 per yard with a ten years' guarantee, and an additional price of 10 cents per yard per year for the next 10 years after the expiration of first guarantee. Assuming the

TABLE No. 53.

Character of Pavement.	Brooklyn.			Boston.			Buffalo.			Chicago.		
	1890.	1900.	1911.	1891.	1900.	1911.	1890.	1900.	1911.	1890.	1900.	1911.
Asphalt	10.85	68.82	424.75	4.65	13.80	21.98	106.03	222.74	239.60	9.24	78.60	530.00
Stone block	83.90	159.95	175.83	69.27	86.97	98.63	140.69	104.50	93.20	23.10	29.77	91.26
Cobble	289.21	236.85	9.43	5.95	1.01	0.29						
Rubble												
Brick		3.78	2.42	0.35	0.80	3.66	0.07	7.47	25.90		29.51	96.03
Macadam	2.81	78.57	110.23	204.57	280.57	353.81	3.28	3.08	15.40	227.01	363.40	574.40
Bitulithic						6.18						
Coal tar and concrete												
Granolithic												
Slag block			1.67									7.48
Wood			2.21			2.61				410.29	763.21	13.59†
												273.59
Miscellaneous											4.88	4.16
Total	386.77	547.97	726.54	284.79	383.15	487.16	250.07	337.79	374.10	669.64	1269.37	1590.51

Character of Pavement.	New York.*			Philadelphia.			St. Louis.			Washington.		
	1890.	1900.	1911.	1891.	1900.	1911.	1890.	1900.	1911.	1890.	1900.	1910.
Asphalt	16.34	162.44	401.31	43.40	254.10	488.90	3.95	11.81	63.80	51.80	129.27	177.34
Stone block	273.75	272.73	148.26	119.60	352.20	392.62	42.46	50.36	71.54	23.50	27.19	26.20
Cobble	3.33	1.10		375.10	69.20	25.81				11.50	11.31	4.08
Rubble				115.50	43.30							
Brick		1.10	0.74	19.80	119.50	168.11		14.23	157.64		0.40	1.40
Macadam	24.23	113.12	139.63	88.80	193.50	303.73	290.08	351.92	269.04	8.00	34.39	89.00
Bitulithic									41.91			
Coal tar and concrete										38.21	14.08	
Granolithic					12.80	12.77						
Slag block			1.54		5.60	5.82						
Wood		0.08	17.70			2.22	5.26	6.89	5.15	0.30		
Miscellaneous												
Total	317.65	550.57	709.18	762.20	1050.20	1399.98	341.75	435.21	609.08	133.31	216.64	298.02

* Manhattan and Bronx. † Creosoted.

interest charge to be 3½ per cent, and the bonds to mature in 20 years, this pavement would cost 15 cents per yard for the first 10 years, and 25 cents per yard for the additional period, but with no other charge, except for maintenance, for the remainder of life.

Table No. 53 shows the pavement mileage of eight of the principal cities of the country in 1890, 1900 and 1911. New York refers simply to the present Boroughs of Manhattan and the Bronx, as in 1890 these boroughs constituted the City of New York. The Borough of Brooklyn has been kept separate in order to show its development.

The table shows a remarkable increase in improved pavements during the last 21 years. Asphalt has increased from 236 to 2347.6 miles, or practically ten-fold. Brick has increased from 20.3 miles to 465.2, or more than twenty-fold. This latter increase is of course in these cities only, and if the cities of the Central West were taken into consideration the increase would undoubtedly be very much greater.

Bitulithic and treated wood are new pavements, both of them having been introduced since 1900 in these cities.

The changes in the character of the pavements of some of these cities are exceedingly striking. In Brooklyn, for instance, cobblestone pavements decreased from 289 miles in 1890 to 9 miles in 1911, and asphalt has increased from 11 miles in 1890 to 425 miles in 1911. In Chicago the asphalt pavements had increased from 9 miles in 1890 to 530 in 1911, while the untreated-wood blocks increased from 410 in 1890 to 763 in 1900, but had decreased to 273 miles in 1911. In New York asphalt pavements had increased from 16 miles to 401 miles and the stone block had decreased from 273 miles in 1890 to 148 miles in 1911. In Philadelphia asphalt had increased from 43 miles in 1891 to 489 miles in 1911, while cobblestone had decreased from 375 miles in 1891 to 26 miles in 1911, and brick had increased from 20 miles in 1890 to 168 miles in 1911. In St. Louis asphalt had increased from 4 miles in 1890 to 64 in 1911, while brick, of which there was none in 1890, reached a mileage of 157 in 1911. In Washington the asphalt had increased from 52 miles in 1890 to 177 miles in 1910. St. Louis and Boston were the only two

cities to report any bitulithic, while all of the cities but Buffalo and Washington reported treated wood.

A great growth of macadam pavement is noted in every city. This class of pavement, however, will undoubtedly decrease in the next 10 years, at least of the character known as water-bound macadam.

CHAPTER VII.

COBBLE AND STONE-BLOCK PAVEMENTS.

Without doubt pavements originated from the necessity of improving low places in roads, which become impassable in wet weather on account of the traffic. This was done successfully, and seemed so desirable that when traffic increased the pavement was extended, and in time it became a necessity over the entire road. To the ancient Romans must be given the honor of being the first to construct roads in Europe on any general system, and to their credit be it said that the work was done in a thorough and substantial manner. These old Roman roads were practically works of solid masonry construction, built of irregularly shaped stones, but finished to a smooth and true surface. A full description of the method of construction of one of these is taken from the French Encyclopedia of 1836.

"1st. A cement of chalk and sand one pouce in thickness.

"2d. On this cement, for the first bed, large stones six pouces thick were placed on one another, and backed by hard mortar.

"3d. A second bed, eight pouces thick, of small round stones, mixed with other broken pieces of building material not so hard, and mixed with a binding cement.

"4th. A third bed, one foot of cement, made of rich earth mixed with chalk."

An ancient pouce was 1.09 inches, and an ordinary pouce 1.06. Fig. 6 shows the ground-plan of a Roman road on the Septimer, as taken from a consular report. Figs. 7 and 8 show sections of other Roman roads.

The Romans constructed these roads all over their conquered provinces, and in after-times the discovery of their remains was taken as proof of former Roman occupation. That the Romans' work was well done is shown by the roads themselves, as the one

previously described is said to have been in good condition fifteen centuries after it was built.

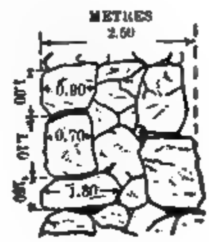


Fig. 6.

Fig. 7.

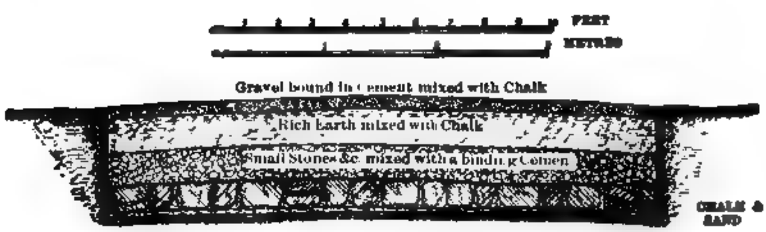


Fig. 8.

The early pavements, however, were constructed in a different manner, the material being in almost every case what is now termed cobblestone. This was natural, as the cobblestones were the most available, and were known to have great durability. As cities grew, and the needs and desires for better streets increased, the rough cobblestone did not satisfy the people, and improved methods were demanded. Attempts were then made to construct a smoother pavement by forming the stones into rude irregular blocks, at first of no particular shape, but endeavoring to give a comparatively smooth surface. This was the beginning of the

modern block pavement. As time passed on, the blocks were made better and the pavements, consequently, were improved.

In Europe, in many cities, the blocks were made several square feet in area, and at first were laid lengthwise of the street, but as traffic increased it was demonstrated that, the long joints being parallel to the wheel traffic wore rapidly, and the pavement soon became rough and uneven. To obviate this, the blocks were made square and were laid as is shown in Fig. 9, which shows a recent

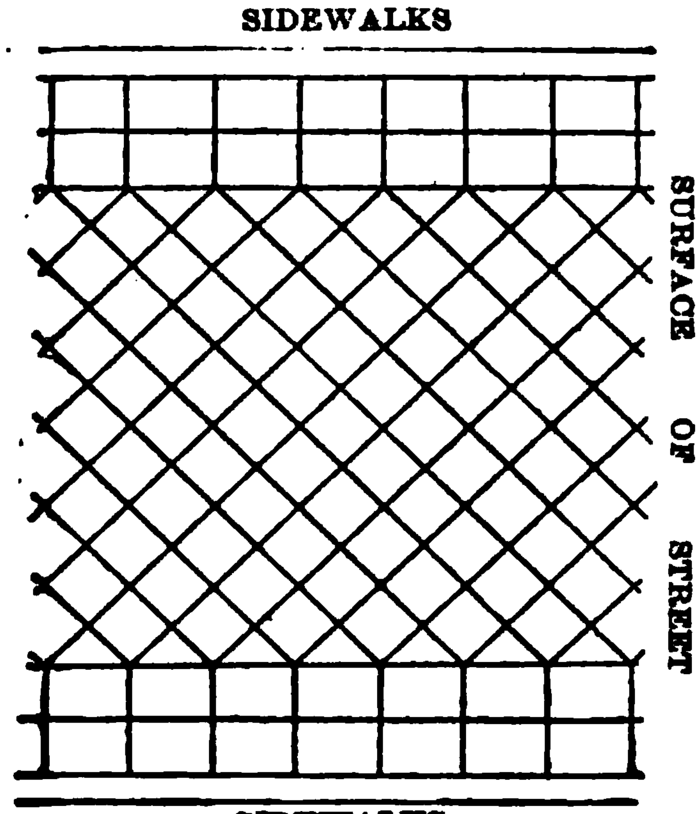


FIG. 9.

street in Catania, Italy. These blocks are of hard lava, 16 × 20 inches square and 8 inches thick. It was soon discovered, also, that these large blocks were not suitable for heavy traffic. It was difficult to get them so bedded on any foundation that they would maintain their position under heavy loads, and the blocks themselves soon became displaced. This caused the blocks to be made smaller still, and the greater portion of the European cities adopted a block about 6 × 8 inches square, and of depths varying according to traffic.

In this country, however, the original pavements were all of cobble. The cities, as a rule, were poor, the cobblestones were available and naturally came into quite common use. They gave very good service, but were necessarily rough, uneven, and very noisy. The Russ blocks spoken of in a previous chapter were probably the only large square blocks that were ever laid in an

American pavement to any great extent, though some were used in New Orleans and Boston.

Following the cobblestone, and in response to the demand for an improvement on them, came what has always been known in this country as the Belgian block. The name is given to it because it was first used in Belgium, and it came to be quite generally adopted in Europe. In shape it was a truncated pyramid, with base about 5 or 6 inches square, and a depth of from 7 to 8 inches, the bottom of the block being of dimensions not more than 1 inch different from the top. This was an improvement on the cobblestone, and when well shaped and of proper material made a very good pavement. In New York and vicinity it became quite popular soon after its adoption, about 1850. The trap-rock forming the Palisades of New Jersey is easily cut into blocks of this shape, and being so near New York, it makes a very cheap and durable paving material. As the blocks became more common, deviations were allowed from the specifications, and the resulting blocks were too small on the base to allow a solid bearing, and under traffic they soon got out of position, and in consequence the pavement became rough. An improvement on the Belgian block was to make the block an exact cube. This was done in the old country, and many cities there at the present time lay blocks that are of that shape.

The question of proper paving material became of so much public importance in Philadelphia that in 1843 a committee of eminent engineers was appointed by the Franklin Institute to examine into the subject and make a report upon the best material for the city of Philadelphia to adopt. After a very careful and thorough investigation of the material being used both in this country and in Europe at that time, the committee made an exhaustive report to the society. After speaking of several experiments of different kinds that had been made in the city, and showing where they were faulty, they finally made the following recommendations for the material to be adopted for the Philadelphia streets.

Streets of the First Class.—These should be paved with dressed stone blocks laid in diagonal courses to the street, upon a subpavement of pebbles. These blocks were to be exactly 8 inches deep and from 7 to 9 inches wide, and 8 to 10 inches long. The estimated

cost of this pavement at that time was $3 per square yard. This pavement was recommended for streets of heavy traffic when the grade was $2^9/_{10}$ per cent or less.

Streets of the Second Class.—The pavement for these streets should consist of two stone tramways built in each street to accommodate traffic in both directions, and the spaces between the trams and curbs to be paved with cobble. It was estimated that this would cost for laying transversely on the streets already paved, and repaving the old material, about $1 per square yard over the entire surface between the curbs.

Streets of the Third Class, including all Lanes and Alleys.—For this the then method of paving with cobbles was recommended, adopting the improvements suggested in the report, which consisted of using more regularly formed stones and thus having the average depth 6 inches. The committee reported as the best shape for the cobblestone "that of a prolate spheroid generated by an ellipse, of which the major axis is double the length of the minor."

A tramway street similar to that proposed for those of the second class had been laid in London in 1825 on the Commercial Road, and the Philadelphians had had an opportunity of seeing one that had been made a short time previous to 1843 on Arch Street.

How much attention was given to this report can be seen from the fact that in 1884 (forty-one years after it was made) ninety-three per cent of the entire pavements of Philadelphia (535 miles) was then paved with cobblestone, as has been before stated.

It did not require, however, many years' experience with Belgian blocks to demonstrate to New York City that the proper pavement had not yet been discovered, and many experiments were made with a view to improvement. About 1865 a patent was issued by the United States to Mr. Charles Guidet for laying granite pavements. The distinctive points of this pavement, and upon which Mr. Guidet based his patent, were:

First, stones bounded by six faces, the two opposite faces being parallel with each other.

Second, the width of the joints running transversely to the street is comparatively wide.

Third, the width of the joints running longitudinally to the street is comparatively narrow.

Pavements under this patent were laid in New York, and several in Brooklyn, about 1869. The cost of those laid by the patentee was about $7 per yard. Not thinking the patent valid or equitable, the city of Brooklyn paved several streets in accordance with this method, without paying any royalty. The patentee brought suit, but was finally beaten in the United States court and the case dismissed. This was the first attempt made in this country, on any extended scale, to lay pavements of oblong blocks.

The different kinds of stone pavement now being used in the United States are the cobblestone, the Belgian block, and the oblong block.

* Cobblestone.

Fortunately for the people who are to come after us, probably no cobblestone pavements are now being laid. In a few cities, however, where property owners pay the first cost of the pavement and are relieved of any further charge for its maintenance or relaying, its cheapness might be sufficient inducement to desire it to be used. It never gives satisfaction, and is really only a substitute for a pavement. If laid in the manner, and of stone, similar to that described by the Philadelphia committee, a tolerably good pavement would be secured, but all stones of that character have now become so scarce that to secure them would increase the cost to such an extent as to make it almost equal to that of the granite pavements.

Cobblestone specifications, too, have been most shamefully abused and violated. As pavements of this class increased and the demand for the stones became so great that suitable ones were obtained only at considerable expense and with some difficulty, almost anything in shape and size was permitted to be used. The result was that cobblestone pavements were even worse than they would have been had they been properly laid. Cobblestone specifications generally provide that the stones shall be the best selected water or bank cobblestones, of a durable and uniform quality, with round heads and well-shaped large ends. They shall not be less than 4 inches nor more than 8 inches in diameter across the head, nor less than 5 inches nor more than 10 inches in depth; no triangular, split, or otherwise ill-shaped stones can be used, nor any which are soft and rotten. The author, once examining a cobble

*** Although both cobblestones and Belgian blocks have become obsolete as paving materials, the matter concerning them is retained for its historical value.**

street, found one stone of such size that he decided to measure it. It was 3 ft. 10 in. long and 11 in. wide, and was probably laid under specifications similar to the above. In another instance, in repaving a cobble street with granite blocks, a boulder was found forming part of the pavement which was so large that it could not be moved without blasting. When the street was paved originally, the boulder found on the street was simply lowered in position until it was at the required grade for the pavement. The cobblestone pavement has had its day and is rapidly passing away, but it exists at the present time in such quantities that it will require several years of active work in repaving in some half a dozen cities to entirely do away with it. Fig. 10 represents a section of a cobblestone pavement.

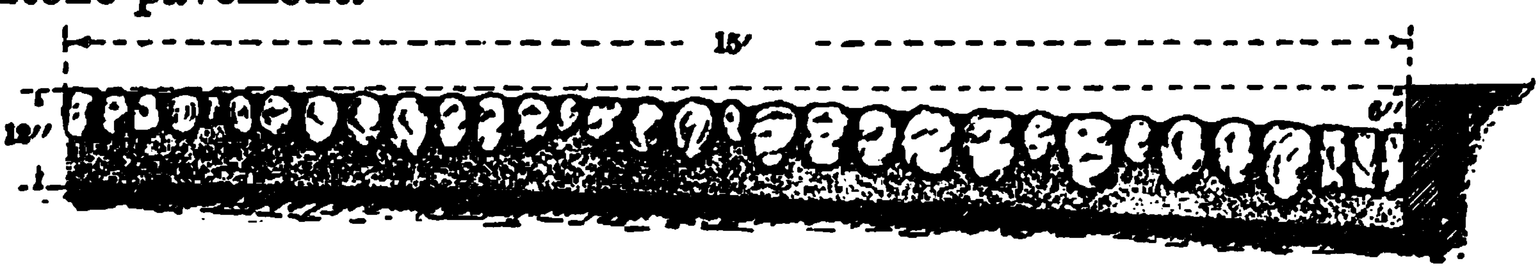


FIG. 10.

According to a bulletin issued by the Department of Labor in 1899, Baltimore, Md., had 5,815,610 sq. yds.; New York City, 4,213,-616 sq. yds.; Philadelphia, 2,920,664 sq. yds.; Cincinnati, 1,213,-000 sq. yds.; and Pittsburgh, 1,147,415 sq. yds. of cobblestone pavement. On Jan. 1, 1912, these amounts had been reduced to the following: 5,200,000 sq. yds. in Baltimore; 135,000 sq. yds. in New York City; 221,000 sq. yds. in Philadelphia; 499,000 sq. yds. in Cincinnati; and 252,000 sq. yds. in Pittsburgh.

In this chapter, and in the entire work, where estimates are given for costs of any kind of pavement, the street is supposed to be graded to subgrade, and any cost of putting it in this condition must be added to the prices herein given. It is customary for paving contractors in and about New York City to deliver paving material on the street and pile it compactly on the sidewalks before the work of paving is begun. The foundation is prepared and laborers called "stone-chuckers" are employed to carry the stones from the side to the pavers. The organization of a gang for laying cobblestone pavement is as follows: One foreman, four pavers, two rammersmen, four chuckers, two men preparing sand base, and two men spreading sand on the completed work. This gang will lay, under favorable conditions, 400 square yards per day.

Assuming the wages as follows:

1 foreman	at	$3.50	per	day	....	$ 3.50
4 pavers	"	4.50	"	"	....	18.00
2 rammersmen	"	3.50	"	"	....	7.00
4 chuckers	"	1.50	"	"	....	6.00
4 laborers	"	1.25	"	"	....	5.00
Total					....	$39.50

for labor for laying 400 square yards of pavement, or 10 cents per square yard for labor.

Assuming sand to cost $1 per cubic yard, delivered on the work, and that 1 cubic yard will lay 5 square yards of pavement, and that the cobbles themselves will cost 40 cents per square yard, the total cost for material will be 60 cents per square yard plus 10 cents for labor, which will make the entire cost of the cobblestone pavement 70 cents per square yard.

In making any estimate upon any kind of pavement, it must be remembered that the cost will vary a considerable percentage according to the contractor, one man making a paying piece of work out of what would perhaps be a losing one to another. The prices of material, too, vary considerably even in the same city, on account of the length of haul, and other local conditions, so that any estimate must be considered a general one unless special conditions for each case are known.

A base for a cobblestone pavement should consist of no less nor much more than 6 inches of loamy sand. If too much or too clean sand be used, the stone will become loose and cannot be maintained in position under traffic. From the shape of the stones, there is nothing in themselves which will serve to bind one to another, so they must be set in a material that will pack solidly and remain in position. In a clean sand the stones will roll, and when no other can be obtained it will be necessary to mix it with a certain percentage of loam in order to get satisfactory results.

Belgian Block.

This pavement in New York and vicinity has been laid almost entirely with the trap-rock from the Palisades of New Jersey. This rock is hard and durable, but after some wear becomes smooth and

slippery. It is so hard, however, that when properly laid it will probably last longer than any stone that is brought to the New York market. On account of its being so generally, and always at first, made of this trap-rock, all trap-rock pavements have been called Belgian pavements, but when made of the oblong blocks similar to those of the ordinary granite they have been called, in distinction, "specification Belgian." This is a complete misnomer, as the name refers distinctly to the shape and not to the character of the material, as some Belgian pavements have been laid of granite.

One great objection to the Belgian pavement is that, on account of the size and shape of the blocks, it will not retain its form under traffic, except upon a very solid foundation. The blocks, too, are of such size as to give a poor foothold to horses, and being square, or nearly so, there is always a considerable length of joints that is parallel to the line of the wheel traffic. This causes the blocks to round off, wear rough, and, at intersections where traffic is very severe, often to be crowded out of position and become rutted. The courses in this pavement, in this country at least, have always been laid parallel to or square with the street. If a square block is to be used, it should be laid in courses diagonal to the street so that no joints should be parallel to the traffic. This, however, would cause some extra expense, but would be more than made up in the benefit that would be derived from this method. In this country the Belgian has been probably laid on a sand base in every instance. The specifications ordinarily recite that the stone blocks are to be of trap-rock, of durable and uniform quality, each measuring on the base, or upper surface, not less than 6 nor more than 8 inches in length, and not less than 4 nor more than 6 inches in width, and of a depth not less than 6 nor more than 8 inches. Blocks of 4 inches in width on their face to be not less than 4 inches at the base. All other blocks of transverse measurement on the base to be not more than 1 inch less than on the face, but no block on the face shall be of less width or length than 4 inches. Blocks laid along curbs must in all cases be 8 inches in depth, and at least one-third of the whole number must be of like depth. The faces of the blocks must be smooth and free from all bunches or depressions.

These variations allowed in the size and shape of the blocks make it very difficult to get a pavement in which the courses are true and the joints well broken. It requires constant care and watchfulness on the part of the inspector to see that blocks in the same courses are of the same width, so that the courses may run evenly and in straight lines across the street, and at the same time have all blocks face snugly up against each other. After the blocks are laid, they should be covered with sand, which must be swept into the joints until they are filled. The blocks should then be rammed to a firm unyielding bed and to a smooth surface. Wherever out of position, the blocks should be trued up and brought perpendicular to the surface of the street and covered with another coat of sand and thoroughly rammed the second time until the pavement is solid and brought to a proper crown and grade. Fig. 11 represents a section of a Belgian block pavement.

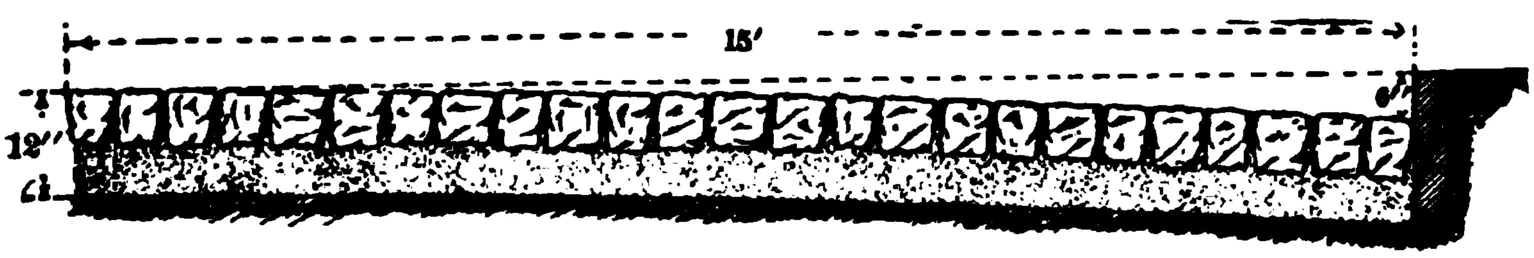


FIG. 11.

Another form for blocks of trap-rock has been used in New York. The blocks are practically of the same size and shape as those of the oblong granite, but on account of the difficulty of breaking trap they are not generally of as true form. Pavements laid of these blocks give much better satisfaction than those of the Belgian and are very durable. They are, however, subject to the same fault as all trap-rocks, that is, of becoming extremely slippery under traffic. While used to quite an extent in New York City, they are not being laid in any amount at present.

On a piece of work laid of this material the organization of the gang was as follows:

5 pavers	at	$4.50	per	day	$22.50
3 rammersmen	"	3.50	"	"	10.50
4 chuckers	"	1.50	"	"	6.00
2 sandmen	"	1.25	"	"	2.50
Making the total for labor					$41.50

This gang laid 350 yards per day. The blocks of which the pavement was laid cost $37 per thousand, $4 for freight, and $1 for hauling, or a total delivered on the work of $42 per thousand, or $4^2/_{10}$ cents each. The blocks laid on an average 27 per square yard. In this particular case the sand was obtained adjacent to the street and practically cost nothing; but assuming it to cost, as in the case of the cobble, 20 cents per square yard, the total cost of the pavement will be for 350 yards:

Labor	$ 41.50
Blocks	396.90
Sand	70.00
Total	$508.40

or $1.43 per yard. The street where this work was done was 44 feet wide.

* On a street paved with Belgian blocks some years ago the paving gang consisted of:

4 pavers	at	$4.50	per	day	$18.00
2 rammers	"	3.50	"	"	7.00
4 chuckers	"	1.50	"	"	6.00
2 laborers	"	1.25	"	"	2.50
Total					$33.50

The amount of pavement laid per day was 240 yards, or a cost of 14 cents per yard for labor. The stone cost about $30 per M delivered on the street, and thirty blocks laid one square yard, making the entire cost of the pavement per square yard:

30 blocks at $30 per M	$0.90
Sand	.20
Labor	.14
Total	$1.24

As the Belgian blocks wore smooth and became rounded off under traffic, considerable dissatisfaction arose with this pavement, and it was soon seen that an improvement was demanded in the

* Since the above observations were made the price of all kinds of labor has materially increased in New York City.

shape of the blocks. Up to this time no great amount of granite had been used in street pavements in this country, so with the improved form of blocks came the introduction of granite as a paving material. The first pavement laid of this character was, as has been said before, the so-called Guidet blocks, but these were large and, while durable under traffic, soon became smooth and slippery. As a modification of this all the blocks were changed into what has generally been adopted for oblong stone blocks.

Granite Pavement.

In making a selection of stone for a block pavement, the hardest does not necessarily give the best results. Any hard stone wears smooth and becomes slippery, and while perhaps it is the most economical for the severest traffic, under medium or ordinary service the softer stone is better. The hard blocks wear on the edges, rounding off from the impact of the horses' shoes, and the face becomes smooth from the abrasion of the wheels, so that in a few years the pavement becomes rough, although the surface of the blocks is smooth. A good example of this is the pavements that have been laid in Chicago and Omaha of the so-called Sioux Falls granite, described in Chapter II. It is extremely durable as far as abrasion is concerned, but cannot be considered a first-class paving material. The softer granites and sandstones, being more tough, do not break on the corners so much, but wear down evenly and smoothly over the entire surface of the block, so that the pavements keep moderately smooth. For light traffic, and perhaps anything less than the heaviest traffic, hard sandstone gives the best results. Although wearing smooth, the character of the material of which they are composed prevents them from being slippery, so that while they may wear out quicker and be less durable, while they are in use the pavement is much better for general traffic.

Limestone blocks have been used very little. They are too soft to sustain much traffic and to wear evenly, so that the surface of the pavement soon becomes rough and uneven. In certain parts of the country, too, the limestone disintegrates when exposed to the atmosphere, so that it is safe to say that the only proper mate-

rial for the stone-block pavement of the present is either a granite or a hard sandstone.

In determining upon the proper dimensions for a paving-block, several questions must be considered.

Length.

A block should be long enough to give a firm bearing on the foundation, and not so long that it will tip up under traffic or fail to conform to the surface of the street, nor so short as to make too many longitudinal joints or present too small a surface for traffic.

Width.

The blocks should be made of such a width as to give a good foothold for horses. The surface of the block itself offers but a slight foothold. The horse must depend upon the shoe-calks catching on the transverse joints of the pavement, so the width of the blocks must not be greater than the difference between the toe- and heel-calks of the ordinary horseshoe, thus reducing to a minimum the tendency to slip. On the other hand, the blocks must not be so narrow as to make the number of joints too many, or to make the face so small as to render the block unstable.

In specifications adopted for paving Havana under a contract partially entered into before the Spanish war and now being carried out, the maximum width of blocks was made 3 inches, on account of mules being principally used for trucking, and their feet being so much smaller than those of the ordinary horse.

Depth.

In determining the depth of the block two principles must be considered: first, the amount of wear to which the block will be subjected; and second, its stability. Probably very few granite pavements are worn out by the direct action of traffic on the surface of the blocks. They become rounded off, displaced, and worn in parts in such a manner as to make the entire pavement rough and uneven rather than from any direct wear of the block itself. So if the block is deep enough to remain firm and solid in its position, it will generally be of sufficient depth to sustain traffic. As a

general rule no block should be laid whose depth is not greater than, and preferably $1\frac{1}{2}$ times, its width. For good results the minimum depth should not be less than 5 inches.

The exact form and shape of the blocks have a great deal to do with the character of the pavement, and a good surface cannot be obtained from poorly shaped blocks.

The engineers of this country for several years have recognized the inferiority of American to European stone pavements. While this has to a certain extent been a fault of construction, it has to a much larger extent been due to the character of the blocks themselves. The cost of the blocks depending so much upon the cost of labor, any increase in the character of the blocks makes a corresponding increase in the character of the pavement; and as the labor of this country is paid much more than corresponding labor in Europe, when the character of the block is improved the cost of the pavement increases in a greater ratio. The use of the automobile and the consequent demand for better pavements that has arisen during the last few years has created a public sentiment which has made it feasible for the engineers to require better blocks despite the attendant increased cost. In 1910 a meeting was held in New York City consisting of engineers of that and neighboring cities and the contractors furnishing granite to that market. The idea was to ascertain how good a block it would be practicable to require without increasing too greatly the cost, and one that could also be furnished by the contractors. The engineers understood that they could require as good a block as they wished, but they also knew that by making their requirements too strong it would be practically impossible for the material men to furnish blocks in any quantity within a reasonable time. On account of the enormous use of asphalt in street pavements during the last 20 years, the use of granite has materially decreased, so that many of the block-makers have returned to the old countries. It was felt that if a reasonably smooth granite pavement could be obtained a much larger amount could be used with satisfaction to the general public. The result of the conference was the following specification was adopted:

"Blocks shall be of the following dimensions: Not less than 8 nor more than 12 inches long on top; not less than $3\frac{1}{2}$ nor more

than $4\frac{1}{2}$ inches wide on top; not less than $4\frac{3}{4}$ nor more than $5\frac{1}{4}$ inches deep. The blocks shall be so dressed that after laying the measurement of the individual joint will show not more than $\frac{1}{2}$ inch in width at top and for a depth of 1 inch, nor more than 1 inch in width in any other part of the joint, provided that not more than 1 drill hole shall show on the side of the head and none on the end of the head of any block. The head of the block shall be so cut that it shall not have more than $\frac{3}{8}$-inch depression from a straight-edge laid in any direction across the head and held parallel to the general surface of the block."

The idea was to adopt a specification that would be acceptable to many cities so that quarrymen would not necessarily have to make blocks for any particular city, but that any blocks in stock could be shipped wherever they were needed. These specifications were adopted in the main as an improved form of pavement in New York and Newark and also by the Association for Standardizing Paving Specifications.

In 1911 when it was proposed to repave Fourth avenue, in the Borough of Manhattan, New York City, from Eighth street to Twenty-third street, with granite, a still better block was required. The blocks were to be so dressed that they should lie with a $\frac{3}{8}$-inch rather than a $\frac{1}{2}$-inch joint, and the top should have no depressions greater than $\frac{1}{4}$ of an inch under a straight-edge. Considerable difficulty has been had in carrying out the specifications, although it is becoming more easy each year after the block-makers have become accustomed to the new requirements.

At a conference held in the spring of 1912 between some of the engineers of the City of New York and the quarrymen, the quarrymen agreed that, while the specifications might allow a variation in width of the blocks from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches, when starting on a contract they would establish a uniform width from which they would not vary more than $\frac{1}{4}$ of an inch. In other words, if a standard of 4 inches were adopted, the blocks would all be within $3\frac{3}{4}$ and $4\frac{1}{4}$ inches in width, and other widths accordingly.

This all goes to show that the tendency is to improve the character of our stone pavements, and if the good work continues for a few years the new granite pavements of this country should compare favorably with those of any country in the world.

When granite blocks were first used in the United States they were laid on a sand base and the depth of the blocks was from 7 to 8 inches. This depth was kept for many years after the concrete base was used, and it seems strange that the fact that this great depth was unnecessary was not discovered earlier than it was, as all engineers had known for some time, if they had but given the matter thought, that a granite block did not wear out by actual wear of the depth of the block, but by its rounding off at the corners and otherwise becoming deformed. The following quotations from the specifications of different cities show how the engineers have met the demand for a better block:

Philadelphia.—" All the faces of the blocks to be true and not warped. They shall be parallel, free from bunches, depressions and inequalities exceeding one-quarter (¼) inch."

Cincinnati.—The blocks shall be substantially rectangular, no departure from the true rectangular shape of more than one-half (½) inch being allowed. The paving face shall be especially well dressed to show no projections or depressions exceeding three-eighths (⅜) inch from a true plane,and shall be so nearly rectangular that the variation in width of an individual block shall not be over three-eighths (⅜) inch, and the variations in length not overone-quarter (¼) inch. All blocks must be so dressed as to allow being laid with the end joints not exceeding three-eighths (⅜) inch and the side joints not exceeding one-half (½) inch for a depth of one and one-half)1½) inches from the tops of the blocks."

Boston.—" The blocks are to be smooth finished on the vertical and ends, the edges are to be sharp and straight, forming right angles at their intersections both horizontally and vertically, and lay close with joints not to exceed one-quarter (¼) inch."

New York.—The size of the blocks shall be as follows: " Not less than seven (7) inches nor more than eleven (11) inches in length, not less than three and one-half (3½) nor more than four and one-half (4½) inches in width, and five (5) nches in depth. A variation of one-quarter (¼) of an inch each way will be allowed in the depth of the blocks. The blocks are to be rectangular, with tops and sides uniform in thickness, lay closely and with a fair and true surface, free from bunches, and so cut or dressed that they can be laid with joints not to exceed one-half (½) inch in width and approximately uniform."

Chicago.—" . . . and be so dressed as to have substantially rectangular plane surfaces, so that where the blocks are in place, the space between the blocks will in no case be less than one-eighth (1/8) inch nor more than three-eighths (3/8) inch."

Montreal.—" The stone blocks must be dressed to present rectangular faces, the six sides of each block must be perfectly true and free from hollows, winding or projections; all blocks whose faces vary more than one-quarter (1/4) of an inch from a rectangular shape, and all blocks having projections or hollows greater than one-quarter (1/4) of an inch on the top, bottom, end or side faces shall be rejected."

Edinburgh, Scotland.—" New paving and setts shall be newly quarried and obtained from the best parts of the quarry approved of, free from cracks or shakes and square dressed throughout in the best manner to within one-quarter (1/4) inch of sizes."

Glasgow.—" Each ordinary sett shall be properly dressed and squared on all its faces, shall be level on the top and bed, and have sides and ends parallel and square. Setts of each class shall be truly gauged. No variation in width or depth greater than one-quarter (1/4) of an inch over or under the sizes specified on orders will be allowed. All setts must be free from cracks or flaws. Setts with bulges or hollows will not be accepted."

It is difficult to keep the contractors to the above specifications, as the block-makers wish to work in all blocks possible and will do their utmost to have them admitted even if they do not conform to the specifications. Some granites break more easily than others. Some stone that is naturally hard, tough, and very durable is bunchy and uneven, so that, while making a durable pavement, it is rough and the width of the joints is apt to vary.

Table No. 54 shows the dimensions of granite blocks used on the principal streets in this country as well as in Great Britain, and Table No. 55 shows the dimensions of blocks used in the principal cities of Europe.

Foundation.

A pavement, as is true of every other work of construction, should have a solid foundation. Without it it is impossible to keep the blocks in position and thus obtain the maximum amount of wear from the pavement. The first granite pavements were laid

TABLE No. 54.

City.	Length, Inches.	Width, Inches.	Depth, Inches.	Remarks.
Boston......	8 to 12	4 to 4½	5 to 5½	
Chicago.....	8 to 12	4 to 5	5	
Cincinnati ..	7 to 12	3½ to 4½	5	¼" variation allowed each way in depth
Montreal....	8 to 14	3 to 4½	5	
New York...	7 to 11	3½ to 4½	4¾ to 5¼	
Philadelphia.	8 to 12	3½ to 4½	6 to 6½	
St. Louis....	9 to 12	3½ to 4½	5 to 6	
Edinburgh...	....	4	6	
Glasgow.....	6 to 10	3½	6	
"	....	3½	7	
"	....	4	6	
"	....	4	7	
Liverpool....	....	3½	6½	First class, 6" concrete base
"	....	3	5	
"	4	4	4	Second class, 6" concrete base
"	4	4	4	Third class, 10" broken-stone base
London.....	5 to 9	3	....	Depth as per drawing

on a sand base, but as traffic increased, both in kind and in weight, it was found necessary to give the blocks a more solid base, and a foundation of cement concrete was adopted in heavy-traffic streets.

The sand foundation is not being used at present to any great extent.

Preparing the Foundation.

Whatever the base, after the street is put to subgrade, the entire surface of the roadway should be thoroughly rolled with a 10-ton roller until it is solid and compact. Should any soft spots develop that will not become solid under the roller, they must be excavated and refilled with firm earth, sand, or gravel and then thoroughly rolled. The subgrade should be brought to the exact coutour as specified for the pavement and the required depth below the finished surface. The sand for the base should be next spread in a sufficient quantity and the paving-blocks laid.

Laying the Blocks.

A few engineers recommend that the blocks should be laid in courses diagonal to the direction of the street. This, however'

TABLE No. 55.

City.	Length, Inches.	Width, Inches.	Depth, Inches.	Remarks.
Aix-la-Chapelle	6⅜	4	7	
Antwerp	5½ to 6½	5½	5½	
Bahia	8 to 12	3 to 6	4 to 6	
Barcelona	7 to 7⅞	3½ to 4	6¼ to 7	
Basle	7	5	6½	
Belfast, Ireland	4	4	4	
" "	4	4	6	
Berlin	7½ to 7⅞	7½ to 7⅞	7½ to 7⅞	
Carthagena	18½	6¾	6 to 6¼	
Copenhagen	7 to 9	4 to 5	7 to 8	
"	6 to 12	3½ to 4½	6½ to 7	
Dresden	1½ times width	5½ to 6¾	6¾ to 7½	First class
		4¾ to 5⅞	5⅞ to 6¾	Second class
		4 to 5⅛	5⅛ to 5⅞	Third class
	6¼	6¼	6¼	Slag blocks
Dublin	7	3¼	6½	
Flanders	7 to 7.8	7	7	
"	6 to 7	6	6	
"	5.7 to 6	5.7	5.7	
"	4.7 to 5.7	4.7	4.7	
Genoa	27½	11⅜	7⅜	Grooved
Leeds, England	6	6	6	
Magdeburg	7½	5½	7	
Nuremberg	6 to 8	5½ to 6¼	5½ to 6	
Paris	9	6¼ to 9	9	Large
"	6¼ to 7⅞	5½ to 7	6¼ to 7⅞	Medium
"	6¼ to 7⅞	4¼ to 5½	4¼ to 7	Small
Palermo, Sicily	18 to 24	18 to 24	8 to 10	Square blocks
Rheims	8	6	6½	
St. Gall, Switzerland	5⅞	5⅞	6¼ to 7	
" "	5⅞	4¾	6¼ to 7	
Trieste	24 to 60	12 to 18	6 to 10	
Valencia	13½	6¾	6	
Vienna	7¼	7¼	7¼	

does not seem to be good practice, as it does not give as good a foothold to the horses, nor will the blocks wear as well as if their courses are at right angles to the street, and this method is almost universally adopted at the present time. A portion of Devonshire Street, Boston, a few years ago was paved with blocks in diagonal courses. Originally the right angle method was continued across all intersecting streets. This was all right for travel on the street being paved, but it was all wrong for the cross-streets, as then it brought the traffic parallel with the blocks, and they soon became unduly worn on the edges and the pavement became rough. This

method is shown in Fig. 12. To remove this difficulty the plan shown in Fig. 13 was adopted, in which the courses are run diagonally to the street paved. This obviated the difficulty for half of the intersection, as it brought that portion of the traffic at right angles to the blocks, as shown by the arrows of the figure, but for the other half of the intersection the traffic remained as before,

FIG. 12.

almost parallel with the blocks. Fig. 14 shows the method which is in use at the present time, and it is as good an arrangement as can be obtained, the principle being to have the traffic, wherever possible, at right angles with the blocks, both on the street proper and at intersections.

The blocks generally should be laid in courses square with the street, stone to stone, and all blocks in the same course to be of uniform width. Too much care cannot be taken in keeping the

joints close, as no matter how tight they may seem to be when laid, they will always show up more loosely after being rammed.

Some contractors purchase their blocks by the thousand, others by the yard. In the former case it is to their interest to have a thousand blocks lay as many yards as possible, and so there is no

FIG. 13.

desire to keep the joints close, or rather there is an inducement for the pavement to be made with large and open joints.

Sand Foundation.

After the blocks are laid they should be covered with a clean, sharp sand, free from pebbles, which shall be swept or raked into the joints until they are filled; each course should then be set up perpendicular to the surface of the street with proper tools, and all

imperfect blocks removed and replaced with good ones, and then the entire surface should be thoroughly rammed. It should then be covered with a second course of sand, treated as before, and rammed the second time. This part of the work should be done with great care. If any soft spot or, as the rammer expresses it, "soft blocks" are found, they should be thoroughly rammed until

FIG. 14.

they are solid and then taken up and the foundation brought to proper grade with added sand, and the blocks replaced and rammed as before. Upon the proper ramming of the pavement depends, in a great measure, how well it will keep its form and shape under traffic. The entire surface of the pavement should be covered with one inch of sand and allowed to remain under traffic a sufficient time to permit all of the joints to be thoroughly filled.

Concrete Foundation.

With this base the subgrade must be treated in the same way as for sand, and the concrete then laid upon it. After the concrete has been completed and set sufficiently so that working upon it will do it no harm, a cushion of sand should be spread over the entire surface. The amount of sand-cushion will depend in a great measure upon the uniformity of the depth of the blocks. If the blocks are of variable depths, the cushion must be deepened, as, on account of the irregularities of the concrete itself, at least 1 inch of sand should be allowed between the bottom of the deepest block and the concrete.

When a stone-block pavement is laid upon a rigid base, the joints between the blocks should be filled with a substance that will make the pavement, as a whole, water-proof. With a sand base this is not desirable or necessary, as, whatever the joint-filling, the blocks, being set on sand, would always have sufficient motion under traffic to permit water to soak through; but with a concrete foundation a perfectly water-tight pavemeut cau easily be obtained' and is desirable both from the sanitary and the physical standpoint.

Joint-filling.

When granite blocks were first laid on a sand base the joints were filled with sand, but when a concrete base was used it was considered that sand was not a satisfactory filler, as, if possible, a watertight pavement was desired. The blocks were supposed to be laid so that joints would be $\frac{3}{4}$ of an inch wide, the same to be filled with gravel, and the interstices of the gravel filled with what was called paving cement. This paving cement was composed of 100 pounds of what was known as commercial No. 4 paving cement, 20 pounds of refined asphalt, and 3 pounds of residuum oil, the asphalt and oil being added to make the resulting compounds less subject to changes of temperature than the coal tar itself would be. The gravel was required to be screened so that it would be retained on a screen having a $\frac{1}{4}$-inch mesh and would pass through a screen having a $\frac{1}{2}$-inch mesh, the idea being to prevent fine gravel or sand from partially filling the voids in the coarse gravel, thus preventing the free running of the cement

through the gravel in the joints. This joint was used for many years, although the author never felt that proper value was received for the cost of the work.

When the joints between the blocks are reduced to ½ inch, if gravel is used it must be smaller, and particular care must be taken to see that the spaces in the gravel are completely filled with the paving composition. In order to do this both the gravel and the paving composition must be hot when used. Both should have a temperature of from 250° to 300° F. This requirement is particularly important in cold weather, when the blocks themselves are cold.

The Liverpool (England) specifications require the joints to be filled with hard, clean, dry shingle, the setts to be then thoroughly rammed and additional shingle added until the joints are perfectly full. The joints then to be carefully grouted until completely filled with a hot composition consisting of coal pitch and creosote oil, and finally the pavement to be covered with ½ inch of sharp gravel.

Portland Cement Joints.

In the last 10 years a considerable amount of granite block pavement has been laid with Portland cement filler in the joints. When the character of the street itself is such that the pavement can be kept perfectly free from traffic for a week or 10 days after the joints are grouted, satisfactory results can be obtained, but it is absolutely necessary that the cement shall be set before traffic is allowed upon the pavement. A street grouted in this way makes, if the tops of the blocks are smooth, a pavement practically as smooth as brick—smooth enough for all ordinary traffic. It is, however, exceedingly difficult in making the repairs to keep the traffic off the patches before the cement has set. The pavement, too, being so smooth, with the joints filled, is more slippery than when the blocks are laid with the open joint.

Another advantage is that it does not require the sides or ends of the blocks to be as carefully dressed, as the grout fills all the inequalities of the blocks and makes the pavement one homogeneous mass. This method of joint filling, however, is used in most cities where the improved granite pavement is being laid.

The grout is generally mixed in the proportion of one of cement to one of sand, and the Newark, N. J., specifications require that this shall be varied according to the hardness of the particular granite to be used on any street, so that the wear of the cement in the joints shall be uniform with the blocks themselves. The Newark specifications also provide that the mortar shall be left on the top of the pavement smooth and even with the highest part of any of the blocks; also, that after the grouting is completed the street shall be kept closed to traffic for at least 7 days and the face of the pavement shall be kept moist, if the condition requires it, either by sprinkling or wetting a coating of sand over the entire surface.

Bituminous Filler.

On the Fourth Avenue (Manhattan) pavement previously referred to, the joints were filled with a bituminous cement, the idea being to have a pavement that would produce as little noise as possible under traffic. The specifications required this cement to be made up of coal tar having a specific gravity not less than 1.23 at 60° F., with a melting-point not less than 130° nor more than 140° F., and containing not less than 22 nor more than 35 per cent free carbon. A bituminous cement filler has not been used to any great extent in this country, although certain compounds have been made which may produce good results.

The specifications of Edinburgh, Scotland, provide for filling as follows:

" The asphalt for grouting causeway joints shall be composed of best quality pitch and creosote oil, boiled together in proportions of about ten (10) cwt. of pitch to fifteen (15) gallons of oil. The pitch shall be free from grit or sand, but contain a sufficient proportion of heavy-nonvolatile oils. The creosote shall be obtained only from coal tar and be of at least 1.06 specific gravity at 60° F. The mixture shall be tempered so that when boiled and cooled in water to 60° F. it shall be capable of stretching out in fine threads at least 36 inches long before rupture, and with a drop 3 feet in length be capable of striking a hard blow on any smooth surface without cracking."

In all block pavements special care should be taken to break

the joints with a lap of at least 3 inches, and preferably in the centre of the block. Where the blocks run of uneven length, the inspector will have to watch pretty carefully to see that this is accomplished. After the blocks have been laid, the gravel, which has been heated to a temperature that will positively insure its being perfectly dry, should be spread over the surface and into the joints in such an amount that when the blocks are rammed the joints shall be filled within 3 inches of the top. The paving-cement should be poured into the joints until they are full to the top of the gravel and until it ceases to run off. The joints should then be filled to the top with more gravel heated to a temperature of not less than 200°, when the joints should be again poured with the paving-cement until they are entirely filled and flush with the surface of the pavement. This part of the work should closely follow that of the pavers, so that when the pavers stop work for the day, the rammers and cement-pourers will require but little time to complete the pavement that is laid. If the gravel, after the joints are filled, becomes wet, it will not properly receive the cement, as any appreciable amount of water always causes it to foam and not form a solid joint. When treated in this manner, a yard of pavement will require about $1\frac{1}{3}$ cubic feet of gravel and $3\frac{1}{2}$ gallons of paving-cement for joint-filling. Fig. 15 represents a section of granite block pavement on a concrete base.

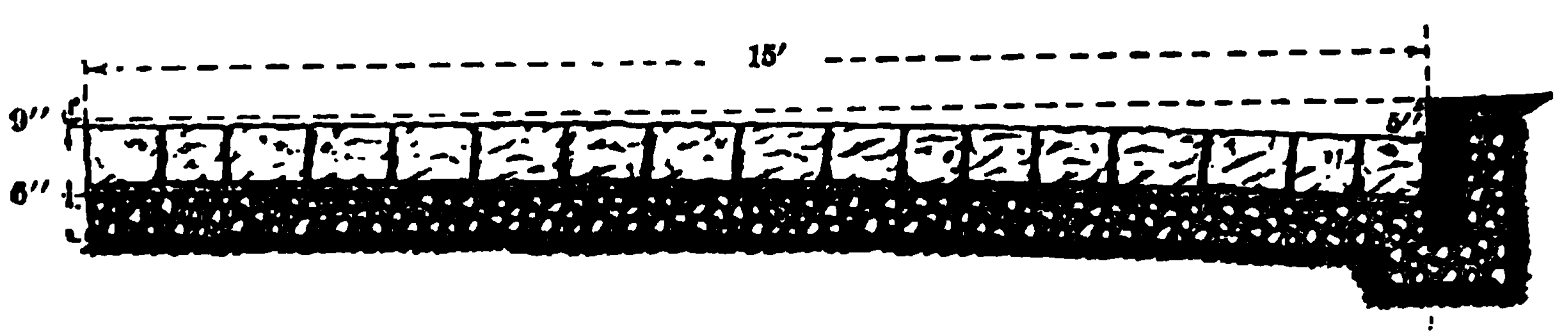


FIG. 15.

Before proceeding with the construction of the base, the cross-section of the street must be determined. This is a question that has been discussed at considerable length by engineers and upon which there is quite a difference in opinion. The best form of the street for traffic alone would be a straight line from one gutter to another, but this would allow the water during any storm to spread out over the entire street, making it difficult for pedestrians to

cross, and also, in case of any settlement of the pavement, holes would be more easily formed.

The early pavements in this country had gutters in the centre, and all the water was therefore led to this portion of the street. By this arrangement the most valuable part of the street was practically given up to drainage, and the water was delivered to the intersecting street at the centre, where it was difficult to take care of it. The remedy for this was to make the surface of the street convex instead of concave, and just how much convexity should be given is a question for discussion. The object of the crown in the street is twofold: first, to give sufficient slope to the pavement to carry the water quickly from the centre to the gutter; and second, to confine the water, in the case of storms, to as small a portion of the street as possible, so as not to interfere with pedestrian travel. When a street is first being paved, and no permanent improvements of any character have been constructed, the problem of the cross-section is comparatively simple. It only remains to adopt a standard depth of gutter and a standard crown, and nothing will interfere with carrying it out. When, however, the street is being repaved and has permanent sidewalks, so that the elevation of the old curbs can be changed but little if any, and one curb is a considerable elevation above the other, the problem is different.

A pavement should be laid with its general surface as nearly uniform as possible, and with but little slope from one side to the other. When, however, the difference in the elevation of the curbs is great, by making different depths of gutter this trouble can be very materially helped.

Two principles govern in determining the depths of gutters. First, they should not be made so deep as to present a high step for pedestrians, nor so shallow as to present little obstruction to wheeled vehicles and to have little water capacity. Unless for some special reason, the gutter should not be deeper than 9 nor less than 4 inches. By thus making the gutter on the high side of the street 9 inches deep, and on the low side 4 inches, the difference of 5 inches is overcome at once, so that with a difference of elevation not greater than 5 inches the crown of the pavement can be put in the centre and the two sides will be symmetrical. If, however, there be a greater difference than 5 inches, the crown can generally

be left in the centre, with an increased difference of 3 or 4 inches, leaving the street with a greater slope on one side than the other.

When the difference becomes so great that the upper side of the street is nearly flat, and the lower side correspondingly steep, the difference can be overcome to a certain extent by changing the crown from the centre to the upper quarter of the street. By giving the crown an arbitrary elevation of 2 or 3 inches, as may be necessary to insure some fall from the crown to the high gutter, the least possible fall from the crown to the lower gutter will be obtained, and the result is a surface that is a compound curve, with the lower three-quarters of one radius and the upper one-quarter of another, not necessarily tangent, but so near it that the difference can never be discovered by the eye.

When, however, street-car tracks are laid, or to be laid, on a street, the problem presents a different phase. While it is not necessary that both tracks should be at the same elevation, it is necessary that the two rails on the same track should be level; therefore it is not possible to fit a track to a curved surface. When there is a material difference between the two curbs, the track on the lower side can be set at the maximum difference of 3 inches below the upper. Then by making the high gutter the maximum depth and the low gutter the minimum, the best possible result is obtained. Possibly, however, in doing this it may be necessary to run the water from the gutter to the centre rather than from the track to the gutter. While this is not desirable, it is not positively bad, and, under circumstances similar to the above, quite often must be done. If the longitudinal grade is considerable and the distance from the car-track to the gutter small, there is no particular objection to making the pavement level or on a straight line from the track to the gutter. When such an arrangement is necessary, the result is often the draining of quite a considerable surface to the tracks where the water runs down to the first intersection, and at that point a catch-basin should be provided between the tracks to take care of it.

Crown.

Very few engineers agree as to the exact amount of crown to be given to a street, and it is also varied according to the material.

Some engineers vary the crown with the longitudinal grade, having a formula by which the crown can be calculated with the different grades. This, however, does not seem to be necessary. Any crown at all is a modification of the best cross-section of the street for traffic designed simply for the purpose of drainage. If then a light crown will drain the street to the gutter, the minimum amount can be used in almost every case, and there seems to be no necessity for running the amount above the minimum unless it is positively required, when it is remembered that the nearer flat a pavement is the more truly it will serve traffic, which is its true province.

Assuming the roadway of the street to be 30 feet wide, and adopting a crown of 4 inches, which does not inconvenience travel, a fall towards the gutter of the central $^1/_3$ will be $^4/_9$ of an inch, or at the rate of 9 inches per 100 feet, which is sufficient for drainage. The fall of the second $^1/_3$ towards the gutter is $1\,^1/_3$ inches, or at the rate of 27 inches per 100 feet, while that of the $^1/_3$ adjacent to the curb is $2^2/_9$ inches, or at the rate of 44 inches per 100 feet.

Table No. 56 gives the fall from the centre to the gutter of each third of the roadway, with different widths and of different crowns.

TABLE No. 56.

Width of Roadway.	Crown.	Fall towards Gutter in Central ⅓ of Roadway.	Rate per 100.	Fall towards Gutter in Second ⅓ of Roadway.	Rate per 100.	Fall to Gutter in ⅓ of Roadway adjacent to Curb.	Rate per 100.
24 feet	3 inches	⅓ inch	8⅓ inches	1 inch	2 ft. 1 in.	1⅔ inches	3 ft. 6 in.
30 "	4 "	4/9 "	9 "	1⅓ inches	2 " 8 "	2 2/9 "	3 " 8 "
30 "	6 "	⅔ "	13⅓ "	2 "	3 " 4 "	3⅓ "	5 " 6 "
36 "	5 "	5/9 "	9¼ "	1⅔ "	2 " 4 "	2 7/9 "	3 " 3 "
48 "	6 "	⅔ "	8⅓ "	2 "	2 " 1 "	3⅓ "	3 " 6 "
60 "	8 "	8/9 "	8 8/9 "	2⅔ "	2 " 8 "	4 4/9 "	3 " 9 "

This table shows very plainly that even on a level grade the water will drain readily from the centre to the gutters, and at the same time the roadway will be such as to be very favorable for travel. Under the heading of Thirty-foot Roadways, figures are given for the 6-inch crown as well as 4-inch, showing how very

materially the side slope increases with the crown, and this side slope, in slippery weather, is much more damaging to horses than a straight horizontal slope.

These figures are recommended as the proper crown on all level streets of improved pavements, except the 6-inch crown on a thirty-foot roadway. The curve of the pavement is in reality a parabola, but in the distance used is practically a circle. It can be best laid out on the crown by stretching a line from curb to curb, and measuring the ordinates down from the line at any desired interval according to the width of the street. The length of the ordinate can be determined by the simple formula

$$O = C\left(\frac{D}{R}\right)^2,$$

in which D is equal to the distance from the centre to any point in feet, R equals $\frac{1}{2}$ the width of roadway, C equals the crown in inches, and O equals the ordinate in inches.

When a street has been laid out in this way and the foundation rolled and prepared as heretofore described, the next work is to lay the concrete; and in order to insure the concrete being laid of the proper thickness, rows of stakes some 10 feet apart longitudinally should be set across the street at intervals of 6 or 8 feet, according to the width of the roadway, and driven to such depth that the tops will be on the same level as that required for the concrete, the proper elevation for the stakes being determined by measuring down from the line in the same manner as for the subgrade.

Concrete.

According to Table No. 24 it is seen that it requires 2.79 barrels of natural cement and 21 cubic feet of sand to make 1 cubic yard of mortar. Ordinary broken stone of uniform size contains about 50 per cent voids, but no commercial broken stone is uniform, as it is more or less graduated in size, so that the voids are generally only 45 per cent. Assuming, then, that the broken stone contains 45 per cent voids, and adding 50 per cent of mortar so as to insure a complete filling of the voids, 1 cubic yard of mortar mixed with 2 cubic yards of stone will make 56.7 cubic feet or 2.1 cubic yards of concrete, and the amount of material necessary for 1 cubic yard

of concrete is 1.33 barrels of cement, 25.7 cubic feet of stone, and 10 cubic feet of sand.

In mixing the concrete, if it is done by hand, platforms will be required for the mixing, some 10 feet square, and for an economical organization two boards should be worked together. The proper organization would be: one foreman and four mixers for each board, four wheelers, one rammer, and one man to carry cement and supply water. Eight wheelbarrows will be required. Enough cement should be mixed in one batch to fill two wheelbarrows, which will be not far from one barrel, but as cement is generally delivered in sacks, it can be easily regulated.

Assuming that the concrete is to be mixed in the proportion of one part cement, two parts sand, and four parts broken stone, the men with the wheelbarrows should wheel four barrows of sand upon the first board, and the cement should be added. The barrowmen should immediately go to the stone-pile and wheel up four barrows of stone, leaving it standing by this board on the barrows, returning again for the other four barrows of stone, and by the time they have reached the board the mixers should have the sand and cement thoroughly incorporated into the mortar, when the barrows of stone should be dumped on the board of mortar and then mixed as described in a previous chapter. The barrowmen should then proceed in the same manner to the other board, and by the time they have furnished it with sand and stone, the mixers on the first board should have the concrete mixed and placed on the street, when the operation should be repeated and continued throughout the day. When hand-work is done, the boards should be situated so near the concrete that the mixers can shovel direct from the board to the face of the concrete, when the rammers should grade and ram it thoroughly until the mortar flushes to the surface and no longer. For this work the expense for material would be:

1.33 bbls. of cement at $1.00	$1.33
.95 cubic yard broken stone at $2.00	1.80
.37 cubic yard sand at $1.30	.48
Total per cubic yard for material	**$3.71**

Or per square yard, 6 inches deep, 62 cents.

FOR LABOR.

1 foreman	$5.00
14 laborers at $1.75	24.50
Total	$29.50

This organization should lay 240 square yards per day, which at the above figures would amount to 12.3 cents per square yard, making a total of 74.3 cents per square yard for hand-mixed concrete.

If, however, the machine described on page 143 and shown in Fig. 5 be used, the organization and results are very different. An engineer would be required to run the engine, and a pair of horses to draw the mixer along as the work progresses. Men are required for setting grade-pegs as before, shovelling material into the machine and wheeling it to the work, and as it is dumped from the wheelbarrows into piles it requires to be raked and graded by laborers for that purpose in addition to the rammers used for handwork, making the organization for the complete outfit:

The following is a proper organization for work with this machine:

1 foreman	$5.00
1 engineer	4.75
1 tally clerk	2.50
7 stone shovellers, at $2.00	14.00
3 sand shovellers, at $2.00	6.00
4 mixing sand and cement, at $2.00	8.00
2 cement men, at $2.00	4.00
3 wheeling sand, at $2.00	6.00
6 wheeling concrete, at $2.00	12.00
3 tampers, at $1.75	5.25
3 rakers, at $1.75	5.25
3 moving planks, at $1.75	5.25
1 handy man, at $2.25	2.25
2 brooming concrete, at $1.75	3.50
1 ton gate man	2.25
1 ton team	6.00
1 team on mixer	6.00
Total	$98.00

This organization will lay in one day of eight hours 1250 square yards of concrete 5 inches thick. This would cost 7.8 cents per square yard, or 56 cents a cubic yard. Materials used per cubic yard would be:

.95 bbl. cement at $1.40	$1.33
.95 cubic yard stone at $2.00	1.90
.50 cubic yard sand at $1.30	.65
Labor as above	.56
Total	$4.44
Per square yard 6 inches thick	$ .74

After the concrete is laid, if the weather be warm, it should be immediately covered with a cushion of sand, and with ordinary cement the pavement can be laid in from 2 to 3 days afterwards, in accordance with the method heretofore described. The particular things which an inspector should watch on a pavement with tar and gravel joints are that the joints are not filled too nearly full with the gravel, and also that the gravel is so nearly uniform in size that it will permit the paving-cement to flow freely through it. If the joints be filled pretty nearly to the top, and the gravel contains any appreciable amount of sand, the paving-cement, instead of running to the bottom of the joint, will flow into the gravel but a very short distance, and while seeming to be full, the joint contains in reality a very small amount of the cement. In order, too, that the cement should flow freely, it should be heated to a temperature of not less than 300° when poured. It should be heated in kettles brought as nearly to the work as possible, so that it will not be cooled in being carried to the work, and that the process of pouring may be done as expeditiously as possible. For work of this character there will be required per square yard of pavement 3½ gallons of paving-cement, 1⅓ cubic feet of gravel, and 1½ cubic feet of sand. The organization of the gang on a piece of work that was carried out recently was:

10 pavers	at $5.00	per day	$50.00
5 rammers	" 4.50	" "	22.50
6 chuckers	" 2.00	" "	12.00
20 laborers	" 2.00	" "	40.00
Total			$124.50

This gang laid on an average 650 yards per day on a street 44 feet wide, and it required 22½ blocks, according to the New York specifications in Table No. 54, per square yard, so that the cost for material would be:

22½ blocks at 7½ cts. each	$1.69
3½ gallons paving-cement at 7 cts	.24½
1⅓ cubic feet gravel at $3.90 per cubic yard.	.19½
1½ cubic feet of sand at $1.30 per cubic yard.	.07
1 square yard of concrete	.74
Labor as above	.19
Total	$3.13

For a granite pavement on sand the organization would be:

4 pavers at $5.00 per day	$20.00
2 rammers " 4.50 " "	9.00
3 chuckers " 2.00 " "	6.00
3 laborers " 2.00 " "	6.00
Total	$41.00

This organization laid 280 square yards per day on a street 30 feet wide free from street-car tracks, at a cost of 12 cents per square yard for labor. On another street where there were street-car-tracks the pavers averaged 63 yards per day instead of 70 as above.

Assuming, then, the sand foundation to be of such depth as to require 1 cubic yard for 5 square yards of pavement, and that 24 blocks will lay a square yard of pavement, the material would cost:

24 blocks at 7½ cts	$1.80
.20 cubic yard of sand at $1.30	.26
Labor	.15
Total on a sand base	$2.21

In all estimates of cost of work, no special pains have been taken to get the exact cost of material, as that must vary very materially with each locality, but the figures used are approximately correct for New York City in 1912. The amount of material required, however, and the amount of work done, are in almost every case the result of actual observation.

For the improved granite blocks in New York in 1912 the approximate price was 1.90 per square yard. With the grout filler the cost should be less than with the tar and gravel wide joints. The close joints filled entirely with pitch would probably be about the same.

Medina Sandstone.

Practically all of the stone pavements of the cities of Cleveland, Rochester and Buffalo are of Medina sandstone. This stone is easily cut into regular shapes, is hard enough so as not to wear unduly under traffic, but at the same time sufficiently soft so that it will wear smoothly and evenly, and is of such a texture that it is not slippery. The specifications for blocks and for laying in these different cities are much the same, though they vary in some particulars. The Cleveland specifications say that the blocks shall not be less than 3½ nor more than 5 inches thick, and not less than 6 nor more than 6½ inches deep, and from 8 to 13 inches long; the stones to have parallel sides and ends, with right angle joints, all roughness of stones to be broken off so that when set in place they shall have tight joints for a distance of at least 3½ inches from the top down. The area of the bottom of any stone to be not less than three-quarters of the area of the top; top to have smooth, even surface.

" Paving blocks " to mean blocks of Medina sandstone prepared in the proper manner for dressed block paving, by nicking and breaking the stones from larger blocks as is done at quarries where such blocks are usually prepared, and not made by redressing or selecting from common stone-paving material; stones to be flat and even at the bottom, which shall be parallel with the top surface, with both top and bottom of stones at right angles to at least one end of the stone so as to set squarely and firmly in place without the use of a paving hammer.

The stones are set tight together in uniform rows, breaking joints at least 2 inches and resting against stones in the same and adjoining course, those of the same class and thickness to be placed together in the same row. The specifications as to the manner of laying the pavement are as follows:

"The pavement shall be laid to the proper grade and crown of the street by using cords or lines stretched lengthwise of the street and drawn tightly over and touching the tops of bed stones set in ballast in the usual manner, as directed; these bed stones to be set in rows lengthwise of the street. Stones to be set from 4 to 6 feet apart each way, as directed, with their tops at the proper grade and crown from the pavement. The lines or cords, when in use, shall always be kept taut and shall extend over not less than three bed stones at a time, or from paving that is laid over not less than two bed stones, making always the three points of support. The pavement after ramming and rolling, or during the process, as may be directed, shall be thoroughly sprinkled or washed with water, to insure the thorough bedding of the blocks, leaving the joints or spaces between the stones their full depth. The joint next to the curb to be 1 inch wide, and to be filled with bituminous cement after the balance of the roadway is grouted."

The joint filling is generally made of Portland cement grout. The cement is mixed with clean, sharp lake sand in a proportion of 1 to 1, measured in boxes. It is then mixed dry in a box and a sufficient amount of water added to make the grout of the proper fluidity when thoroughly stirred.

The grout is prepared only in small quantities and stirred rapidly and constantly in a box while being applied to the pavement, and is swept rapidly into the joints with proper brooms. The filling is done by two or more applications of the grout. The first two-thirds in depth of the joints from the bottom are filled with the grout somewhat thinner than is required for the remaining one-third. The remainder of the joints is then filled with a thicker grout and if necessary refilled until the joints remain full to the top. This pavement costs in Cleveland $3.00 per yard.

The Rochester specifications provide that the blocks shall be not less than 3 nor more than 6 inches thick, and not less than 6 nor more than 6½ inches deep, and from 7 to 12 inches in length. The stones to have parallel sides and ends and right-angle joints; all roughness in joints of stones to be broken off, so that when set in place they shall have tight joints for a distance at least 2½ inches from the top down. The top to have a smooth, even surface, with no projection or depression exceeding ¼ inch. Pro-

vision is made, however, that upon the approval of the City Engineer blocks can be used that are 3 to 5 inches in width and 5 inches in depth (with an allowable variation of ½ inch more or less in said depth), and 7 to 12 inches in length.

The blocks are laid upon a foundation of 6 inches of Portland cement concrete and a cushion of sand not less than 1 inch in thickness. Blocks are laid so that all longitudinal or end joints shall be close joints and be broken by a lap of at least 3 inches, but with joints between courses that shall not exceed ½ inch in width. The blocks are rammed by courses at least three times by a rammer weighing not less than 80 pounds, provision being made that no iron shall come in contact with the paving. The surface of the pavement when completed to be even and smooth throughout and moulded to conform to the wells of the surface sewers, street and alley intersections, drainage details and the grade lines established by the City Engineer. During the final ramming the pavement is tested with a straightedge and templet and any unevenness taken out and made true.

Both paving pitch and cement grout fillers are used. With the paving pitch filler the joints are first filled with dry, hot gravel of such size that it will pass through a sieve having 4 meshes per square inch and be retained on a sieve of 64 meshes per square inch. The joints are then poured full with the paving cement heated to a temperature of 300° F. Dry, hot gravel is then poured along the joints that have been filled with the paving-cement.

If a Portland-cement grout is used for filler it is of practically the same qualities as that described in the Cleveland specifications and applied in practically the same manner.

The specifications further provide that no teams shall be allowed on the pavement for 10 days after the grout is applied, or until in the opinion of the Engineer it has become thoroughly set. This pavement also costs in Rochester $3.00 per yard.

Cross-walks.

At each intersection in stone pavements, cross-walks must be laid to accommodate pedestrian travel. It has been customary in New York to lay cross-walks of Hudson River bluestone in all cob-

ble and Belgian pavements, and granite cross-walks where the streets are paved with granite. In the West, where sandstone is used for paving, the cross-walks are made of the same material. The bluestone cross-walks in New York consist of two courses of Hudson River bluestone 2 feet wide and from 6 to 8 inches thick, separated by one course of granite or Belgian blocks, their length being not less than 4 nor more than 6 feet. The granite cross-walks as at present used in New York are not less than 4 nor more than 6 feet in length, 1½ feet wide, and not less than 6 nor more than 8 inches thick throughout. Cross-walks were originally laid with the end joints parallel to the line of the street, as shown at *A*, Fig. 12. This gives a joint 18 inches or 2 feet in length, according to the kind of stone, parallel to the traffic. In a few years these joints always wear badly, so that a rut is formed, especially, as is often the case, if the joint was not squared to its full depth. To obviate this the joints were cut diagonally with a slope of about 6 inches in the width of the stone, so that no traffic would be parallel to the joint. At first they were all as shown at *B* in Fig. 13, but, as in the case of the blocks laid on the intersection, this was objectionable, as it made the joints parallel to the traffic turning the corner. The proper way is to lay them as shown at *C* and *D* in Fig. 14, with a keystone in the centre, so that the joint is always opposed to the traffic.

It is customary in most cities to construct sewers with catch-basins for storm-water at the curb-corners of the intersections. This makes it necessary to carry the water over the cross-walk, and if there is an appreciable step from the pavement to the curb, it is better to stop the cross-walk within about 6 inches of the curb and depress the blocks in the intervening space so that the water can run down the gutter at the end of the crossing, unless the fall be too great. A much better arrangement, however, can be had if, instead of one basin at the corner, two smaller basins could be put back of the cross-walk, as shown at *E* and *F*, Fig. 14. This would allow the intersection to be paved almost to a level with the curb, and so that the street would present practically no obstruction to pedestrian travel. When it is considered how much money is expended in the paving of a street in order to make it convenient for the public, it would seem that the little extra expense neces-

sary for this improvement would be justified when the results obtained are considered.

Granite Pavement in Vienna.

Cubes are mostly employed measuring 7¼ inches. On streets having a grade of 1 in 50 the blocks are laid at an angle of 45° to the line of the street. On grades up to 1 in 40 they are laid at right angles to the street line. If the grade is more than 1 in 40, cubes measuring about 5¼ inches are used, also set at right angles to the street. But if the grade is more than 1 in 33, the smaller blocks are grooved to provide a foothold for horses. The blocks are laid on a foundation of 6 inches of gravel, upon which is a sand-cushion of 1⅛ inches.

Generally the joints are filled with sand, but on heavy traffic and built-up streets an asphalt filler is used for the joints. This asphalt filler increases the cost about 30 cents per square yard. The average price of the pavement is from $2.60 to $3 per yard.

CHAPTER VIII.

ASPHALT AND BITULITHIC PAVEMENTS.

THE early history of asphalt pavements in Europe was pretty generally given in the chapter on the history of pavements.

In the United States, previous to 1866, sidewalks and cross-walks had been laid in Lock Haven, Pa., of coal-tar mixed with gravel, broken stone, coal-ashes, etc., under a special patent issued to a Mr. Scrimshaw, from whom the name of the pavement was derived. In 1867 a small portion of the roadway of one of the drives in Prospect Park, Brooklyn, was paved with the same material. So successful was that experiment that the following year a similar pavement was laid on Diamond Street, now Lenox Road, Flatbush, L. I. The foundation consisted of a course of 2-inch broken stone 5 inches thick, mixed with sand, coal-ashes, and tar. The wearing surface was similar to the foundation, except that no stone was used greater than 1 inch in any dimension. This made a pavement that lasted for more than twenty years, and when the street was repaved in 1896 some of it was found intact and served as a foundation for the new asphalt pavement. This street was probably the first one regularly paved with a bituminous material in the United States.

Such pavements gave good satisfaction as long as a good quality of tar could be obtained, but on account of the large amount of volatile oils contained in the tar it was necessary to close a street to travel for about thirty days after its completion, and with some tars fifty and even sixty days. This was objectionable, and the difficulty was obviated in 1871 by a combination of roofing-pitch and creosote, or dead oil, which combination was patented in March of that year by a Mr. B. Abbott. With this material a better pavement was laid, and one that could be used the following day. This was known as the Abbott patent. Streets were paved under this

patent in Brooklyn and Washington which were in good condition for fourteen or fifteen years. Some of the old Brooklyn pavements are found even now when some of the older asphalt pavements are being relaid. As coal-tar pavements failed, asphalt was laid over the tar as a foundation

In 1878 Delaware Avenue, Buffalo, was paved with Trinidad asphalt, fluxed with still wax, or wax tailings. This still wax was a waxy oil, dark green in color, being the last product of the distillation of petroleum before coke is reached, and was free from all oils that would be driven off at a temperature of less than 600 degrees. According to the report of the Board of Public Works in Buffalo, this street cost for repairs a total amount of $515 until it was relaid in 1892.

In the Delaware Avenue pavement sand was not used for a matrix, but instead a hard broken stone, screened to exclude all above ½ inch in size and to permit smaller stones even down to dust. Before long, however, chemical research had discovered other and more valuable uses for the wax, and it became too expensive for street use, and recourse was had to residuum oil.

In the mean time coal-tar streets of different mixtures had been laid in Washington soon after 1870. They were laid under a good many different patents, of as many different mixtures, receiving their name generally from that of the patentee. The base was generally made up of broken stone 4 to 6 inches thick, cemented together with coal-tar and covered with a binder coat about 1 inch thick composed of pebbles, fine broken stone, and coal-tar. The difference in the pavement was in the wearing surface, which varied according to the patents, but coal-tar was the cementing material. Some of these failed very quickly. Of 187,271 square yards of the Evans pavement laid in 1872–3 at a cost of $3.20 per yard, over 150,000 yards were resurfaced within two years. Others stood much better, some not being resurfaced for six or seven years, and quite a number lasted even ten and fifteen years.

In the report of the Engineering Department of the District of Columbia, in 1887, Captain Griffin says:

"The mean average expense for maintenance of 745,305 square yards is 5.5 cents per square yard for fifteen years. That a durable coal-tar pavement can be laid is proven by the fact that the vul-

canite pavements have only averaged 2.9 cents per square yard per annum."

So expensive were these coal-tar pavements to maintain that Lieutenant Hoxie, in 1887, estimated that their cost would be 20 cents per yard per annum, so that when the first Board of Commissioners appointed under Act of June 11, 1878, came into office, they expressed themselves as follows on this subject:

"In determining the class of pavements to be hereafter laid, the commissioners maintain that each class of pavement must prove its quality under test of actual traffic before being extensively laid upon the streets of this city.

"While some of the later and better class of coal-tar pavements show good service and give a fair promise of reasonable durability, yet the general condition of this class of pavements in the city is such as to lead to their condemnation as faulty in principle and deficient in vitality.

"The use of bituminous bases has also given rise to many perplexing problems in the grades of streets upon which they have been laid, and as, when properly laid, their cost is as great as, if not greater than, hydraulic concrete, they have been definitely abandoned."

In 1886–87 Congress passed a law which provided that no contract should be made for making or repairing concrete or asphalt pavements at a higher price than $2 per square yard, of a quality equal to the best laid in the District prior to July 1, 1886, and with the same depth of base. The lowest bid for asphalt pavements received immediately after the passage of this act was $2.25, which could not be accepted, and the city was obliged to return to coal-tar pavements and those of asphalt block.

The specifications for these coal-tar pavements provided that the base and binder should be 4½ inches thick and laid as follows:

"The base will be composed of clean broken stone that will pass through a 3-inch screen, well rammed and rolled with a steam-roller, to a depth of 4 inches, and thoroughly coated with hot paving-cement composed of the best No. 4 coal-tar distillate, in the proportion of about 1 gallon to the square yard of pavement. The second binder course will be composed of clean broken stone thoroughly screened, not exceeding 1¼ inches in dimension, and No. 4

coal-tar distillate. The stone will be heated by passing through revolving heaters and thoroughly mixed by machinery with the distillate in the proportion of one gallon of distillate to one cubic foot of stone. The binder will be hauled to the work, spread upon the base course at least two inches thick, and immediately rammed and rolled with hand and heavy steam rollers while in a hot and plastic condition. The wearing surface will be 1½ inches thick when compacted, made of paving-cement composed of 25 per cent asphalt and 75 per cent coal-tar distillate, mixed with other materials as follows:

"Clean, sharp sand will be mixed with pulverized stone, of such dimensions as to pass through a ¼-inch screen, in the proportion of 2 to 1.

"To 21 cubic feet of the above-named mixture will be added 1 peck of dry hydraulic cement, 1 quart of flour of sulphur, and 2 quarts of air-slacked lime. To this mixture will be added 320 lbs. of paving-cement to compose the wearing surface."

This material was laid on the street in practically the same manner as asphalt pavement is at the present time.

The coal-tar pavements laid in 1887 cost 4.65 cents per yard per year for maintenance for ten years, and those laid in 1888 cost 5.96 cents per yard per year for a period of nine years. At the end of ten years it was found necessary to relay some of them and substitute standard asphalt, and future repairs will be made in the same manner.

From a table published in the report of the Engineering Department of the District of Columbia, in the fiscal years 1886–87, it is shown that the annual expenditure for the maintenance of coal-tar pavements for fifteen years ending July 1, 1886, had been 7.2 cents per square yard.

These pavements being laid on a bituminous base become practically a part of the base, and in repaving them it is necessary to take up the entire pavement; while if they had been laid on a hydraulic-cement concrete base, it would only have been necessary to have renewed the wearing surface.

The fact that these coal-tar pavements did not give complete satisfaction, and were expensive to maintain, led people interested in the subject to make experiments with other material.

Mr. E. J. de Smedt, who had taken out several patents and had made many experiments, laid a bituminous pavement in Newark, N. J., in front of the City Hall in 1870, with Trinidad asphalt as the cementing material. This was without doubt the first asphalt pavement laid in the United States. It was followed by another similar one in New York City near the Battery in 1871, and soon after by another in Philadelphia, and in a few years still more in New York City. These pavements gave such satisfactory results that they attracted the attention of the authorities in Washington, and a special commission was appointed by Congress to investigate and report as to the advisability of adopting them in Washington. As a result of the commissioners' report Pennsylvania Avenue from First Street to Sixth Street was paved with rock asphalt by the Neuchatel Asphalt Co. in 1876–77, and from Sixth Street to Fifteenth Street at the same time with Trinidad asphalt. These pavements gave good satisfaction, except that the rock asphalt was so slippery that when the street was resurfaced in 1890 Trinidad asphalt was laid over the entire area. The success of asphalt in Washington may be considered as settling to a great extent the experimental nature of the pavement, and from that time on its success has been assured and its use has continually increased.

In many respects asphalt makes a perfect pavement. It will sustain travel without being damaged, and in fact is benefited by quite severe traffic. It is smooth, pleasant to drive over, almost noiseless for carriages, and can be kept absolutely clean. It is impervious to water or moisture and, consequently, as a sanitary pavement is without a rival. It is considered by some to be expensive, and it is, as compared with some of the coarser rock pavements, but very few who have once used it are willing to give it up, or doubt that they have received the value of their money.

Many asphalt pavements have failed, and have required considerable resurfacing sooner than they should; but when it is remembered how new the industry is, how rapidly it has been developed, that there was no precedent for the mixtures, and that the principal mode of treatment, as well as the percentages of materials to be used, had to be determined by actual practice and experiment, the wonder is that not so many but that so few pavements have failed.

One of the objections made to asphalt is on account of its slipperiness and the liability of horses falling when they come off from a rough stone surface to the smooth asphalt. There is some reason in this, but as asphalt pavements increase in quantity, horses will become more accustomed to them and learn to adapt themselves to the smooth surface. Asphalt itself, contrary to the general belief, is not slippery. It is smooth, and any soft substance upon a smooth surface makes it slippery. Asphalt pavements should be kept clean and then there will be less trouble on account of horses slipping. Asphalt is much less slippery when dry than when slightly damp or moist. It is well known to truckmen that horses travel on a smooth pavement much more easily during a heavy rain than in a drizzle. A certain amount of street detritus must collect on any smooth pavement, and when rain falls in a quantity sufficient to wet it only rather than wash it clean, it must be slippery to a certain extent.

The question as to what is the steepest grade on which it is safe to lay asphalt has received a great deal of study. When the material was first introduced grades of 4 per cent were considered prohibitory, and very little was laid on those exceeding 3 per cent, but practice soon showed that this was too conservative a view, and as a result pavements have been laid successfully and quite frequently on grades as high as 7 and 8 per cent, and in Scranton, Pa., there is a portion of one street that has a grade of 12½ per cent. It was said to have been placed on this particular block for the sake of preventing traffic, but, strange to say, it has not done so, and the City Engineer says that after several years' use no great trouble has been experienced with it.

Fig. 16 represents a profile of a portion of Bates Street, Pittsburgh, Pa. This shows that the elevation of the grade increased from 188.21 at the property line to 209.63 at a point 200 feet distant, making an average rise of 10.7 per cent. Instead, however, of making a uniform grade, these points were connected by a vertical curve, making in one section a grade of 17.1 per cent, and in the first 80 feet the minimum rate is 12.4 per cent. This street is paved with sheet asphalt, and without doubt has the steepest grade of any street in the world paved with that material.

As a rule, however, asphalt should not be laid on a street that

will be subjected to any material amount of traffic on grades exceeding 6 per cent, for there must be certain times of the year when they can be used but little and with considerable difficulty. On residence streets, however, where traffic is light, the people are willing in many cases to put up with the inconvenience of the slippery streets on a comparatively few days of the year for the sake of hav-

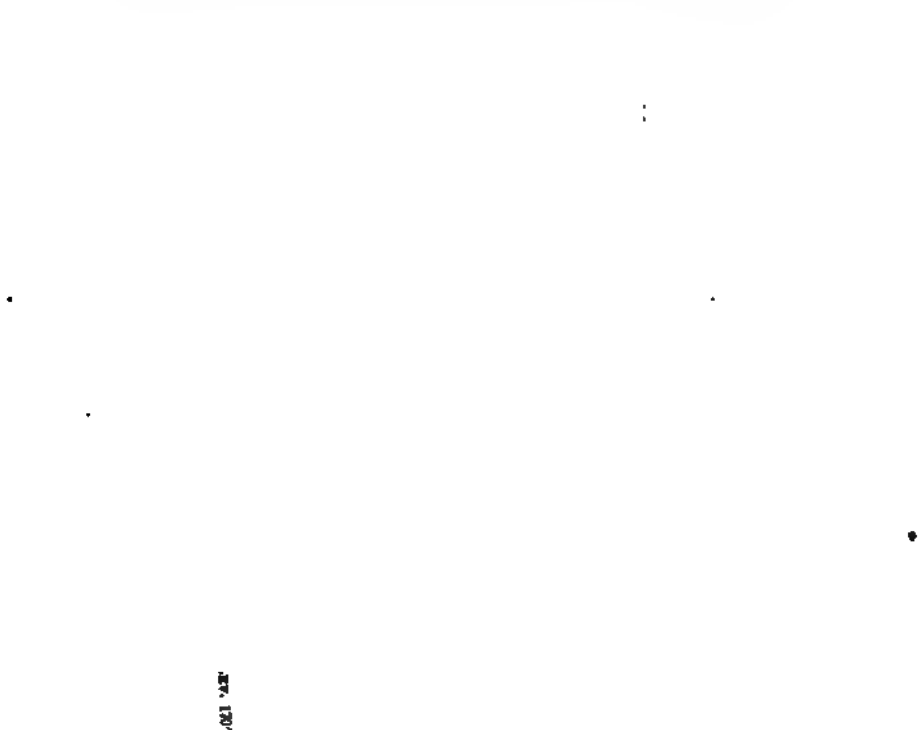


FIG. 16.

ing smooth, clean, noiseless pavements for the remainder of the time.

In New York City, where a street has been paved on a 6 per cent grade with asphalt on the sides and granite in the centre, as a rule the traffic seeks the smooth asphalt with its ease of traction, rather than take the granite.

Asphalt pavements are now in use upon grades in different cities as shown on page 235.

	Per cent.
New York City............................	6
Omaha, Nebraska..........................	7 to 8
Brooklyn, N. Y...........................	4½
Syracuse, N. Y...........................	7
Scranton, Pa.............................	12½

The crown of pavements has been thoroughly discussed in the chapter on Stone Pavements, and the remarks made there will apply with equal force to asphalt.

Table No. 57 shows the method adopted by the Author for laying

TABLE No. 57.

CROSS-SECTIONS TO BE USED IN LAYING ASPHALT PAVEMENTS; SHOWING MEASUREMENTS FROM A LINE DRAWN FROM CURB TO CURB TO THE FINISHED PAVEMENT.

Measurements to Finished Surface.

		Curb.	⅜ from.	⅛ from	Centre.	⅛ from.	⅜ from.	Curb
				4″ GUTTERS.				
Centre 2″ above line	(6″ crown)	4″	¾″	1¼″ ab.	2″ above	1¼″ ab.	¾″	4″
" 1″ " "	(5″ ")	4″	1¼″	½″ above	1″ above	½″ above	1¼″	4″
" even with "	(4″ ")	4″	1¾″	½″	0	½″	1¾″	4″
				4″ × 5″ GUTTERS.				
Centre 1½″ above line	(6″ crown)	4″	¾″	1″ above	1½″ ab.	¾″ above	1½″	5″
" ½″ " "	(5″ ")	4″	1½″	0	½″ above	¼″	2″	5″
" ½″ below "	(4″ ")	4″	2″	¾″	½″	1″	2½″	5″
				4″ × 6″ GUTTERS.				
Centre 1″ above line	(6″ crown)	4″	1″	¾″ above	1″ above	0	2¼″	6″
" even with "	(5″ ")	4″	1½″	¼″	0	1″	3″	6″
" 1″ below "	(4″ ")	4″	2″	1″	1″	1¾″	3½″	6″
				4″ × 7″ GUTTERS.				
Centre ½″ above line	(6″ crown)	4″	1¼″	¼″ above	½″ above	¾″ above	3¼″	7″
" ½″ below "	(5″ ")	4″	1¾″	½″	½″	1½″	3¾″	7″
" 1½″ " "	(4″ ")	4″	2¼″	1½″	1½″	2½″	4¼″	7″
				4″ × 8″ GUTTERS.				
Centre even with line	(6″ crown)	4″	1¼″	0	0	1¼″	4″	8″
" 1″ below "	(5″ ")	4″	2″	1″	1″	2¼″	4½″	8″
" 2″ " "	(4″ ")	4″	2½″	1¾″	2″	3″	5″	8″
				4″ × 9″ GUTTERS.				
Centre ½″ below line	(6″ crown)	4″	1½″	¼″	½″	2″	4¾″	9″
" 1½″ " "	(5″ ")	4″	2″	1¼″	1½″	3″	[illegible]½″	9″
" 2½″ " "	(4″ ")	4″	2½″	2″	2½″	3¾″	6″	9″
				5″ GUTTERS.				
Centre 1″ above line	(6″ crown)	5″	1¾″	¼″ above	1″ above	¼″ above	1¾″	5″
" even with "	(5″ ")	5″	2¼″	½″	0	½″	2¼″	5″
" 1″ below "	(4″ ")	5″	2¾″	1½″	1″	1½″	2¾″	5″
				6″ GUTTERS.				
Centre even with line	(6″ crown)	6″	2¾″	¾″	0	¾″	2¾″	6″
" 1″ below "	(5″ ")	6″	3¼″	1½″	1″	1½″	3¼″	6″
" 2″ " "	(4″ ")	6″	3¾″	2½″	2″	2½″	3¾″	6″

out the cross-section of asphalt pavements with different depths of gutter, the surfaces being obtained in the same manner as with stone pavement, by measuring down at stated intervals from a line stretched from curb to curb.

Character of Asphalt.

To make a first-class pavement, asphalt should be of a good character, properly mixed with the right materials, and well laid upon a good foundation. Whether untried asphalt will or will not make a good pavement can only be settled by actual use. A chemist can analyze it, tell what are its component parts, give its physical properties, as well as his idea as to what it ought to do, but cannot tell positively how it will act in a pavement. The asphalt on Eighth Avenue, New York City, laid in 1890, probably has received more notice than that laid on any other street in this country. Stephenson Towle, at that time Consulting Engineer of New York, in speaking of this pavement in his report to the Commissioner of Public Works in January, 1895, said:

"This asphalt was submitted to and approved by experts and chemists before the contract was entered into. Soon after the pavement was laid, and before its completion [it has never been accepted], it showed unmistakable evidences of disintegration. This failure was exceptional, and the experts and chemists who had approved of the asphalt could not account for it. My own belief was that the asphalt was inferior or lacking in some essential property unknown to chemists."

While all asphalt contains bitumen, all bitumen will not make a good pavement, no matter with what it is fluxed. Certain varieties of asphalt will be brittle and not possess the cementitious properties necessary to hold the sand together. An asphalt pavement is really an asphaltic concrete in which particles of sand are held together by the cementing properties of the asphalt, and if for any reason the asphalt loses the cementing properties, the pavement must disintegrate and fail. Some asphalts, however, while not suitable for pavements in themselves, can, by being mixed with proper quantities of other bitumens by people who understand the nature of the material, be made into a valuable cementing sub-

stance. A poor asphalt treated by an expert is liable to make a better pavement than good material handled by poor and inexperienced workmen. A new asphalt should be laid two or three years at least before it is safe to pass an opinion upon it as to its durability. If laid, as it generally is, in the summer, the winter season subjects the material to a severe test. The cold weather causes it to contract, and if laid too hard, it is apt to crack and, if the cold continues, crumble to a certain extent. In a previous chapter reference has been made as to the proper method for the chemist to examine new asphalts.

When petroleum residuum is used as a flux it is sometimes first mixed with a so-called asphalt, often termed "Pittsburg flux." The Washington reports say that a pavement was improved by this process, and that the asphaltic cement was made by mixing 100 lbs. of refined asphalt, 14 lbs. residuum, and 11 lbs. Pittsburg flux. Pittsburg flux is manufactured by heating petroleum residuum with sulphur, the sulphur combining with portions of the hydrogen of the petroleum and escaping as hydrogen sulphide gas, leaving the product as a residue. The usual amount of residuum used to flux Trinidad asphalt is about 18 lbs. of oil to 100 lbs. of refined asphalt. When maltha and asphaltic oils are used, the amount must be determined both by the character of the flux and also of the refined asphalt.

Asphaltic Cement.

Whatever the character of the crude and refined asphalt, it is the asphaltic cement upon which the success of the pavement depends. The asphaltic cement should be tough and elastic; should be adhesive so as to hold the particles of sand together, and cohesive so as not to disintegrate. It should be capable of resisting changes of temperature of over 30° below zero and 140° above, as it will in many instances be subjected to these temperatures in pavements. Observations taken in Washington when the temperature of the air was 104°, about 2 feet above the pavement, showed the asphalt itself to be at a temperature of 140°, while the temperature of macadam at the same time was 118°. In St. Paul, Minn., and Omaha, Neb., pavements in the winter will be subjected to

temperatures of 30° below zero, although not very often. It would be quite safe to predict that an asphaltic cement that would comply with the conditions as given above would make a good pavement.

For some time it has been contended by certain experts that specifications for asphalt pavement should not make any requirement for the asphalt itself but only for the asphaltic cement, and that engineers should call for results and not methods of obtaining them. As a general proposition this is correct, and it is probable that specifications might be made for an asphaltic cement so that a good pavement will be secured when laid. How long the asphaltic cement will maintain the characteristics it possessed when first laid is another proposition. Hard and dry asphalts can be so treated bythe addition of certain fluxes that they will make a suitable asphalt pavement, but, on account of the volatile character of the fluxes, will not maintain these characteristics, and consequently if used in a pavement will not give satisfaction. This fact is so well recognized by experts that some chemists will not allow certain kinds of fluxes to be used, fearing that an asphaltic cement may be made that will be temporarily good, but that will fail in a comparatively short time.

At the third annual meeting of the Association for Standardizing Paving Specifications, held in New Orleans in January, 1912, the Committee on Asphalt Paving Specifications was quite liberal in its report. The specifications of the Association for refined asphalt, fluxes and asphaltic cement are as follows:

"*Refined Asphalt.*—The refined asphalt to be used for paving mixtures herein required shall be derived in the following manner:

"1. By heating, if requiring refinement, crude, natural, solid asphalt, to a temperature of not over 450° F., until all the water has been driven off. Crude, natural, solid asphalt shall be construed to mean any natural mineral bitumen, either pure or mixed with foreign matter, from which through natural causes in the process of time the light oils have been driven off until it has a consistency harder than 100 penetration at 77° F. At least 98½ per cent of the contained bitumen in the refined asphalt which is soluble in cold carbon disulphide, shall be soluble in cold carbon tetrachloride. In no case shall such asphalt be

prepared at tne refinery with any product not hereinafter provided for.

"2. By the careful distillation of asphaltic petroleum with continuous agitation until the resulting bitumen has a consistency not harder than 30 penetration at 77° F.

"(*a*) All shipments of material shall be marked with a lot number and penetration, and ten samples taken at random from each lot shall not vary more than 15 per cent from the average penetration, providing no part of any shipment shall be below 30 penetration at 77° F.

"(*b*) The solid bitumen so obtained shall be soluble in carbon tetrachloride to the extent of 98½ per cent.

"(*c*) When 20 grams of the material are heated for five (5) hours at a temperature of 325° F. in a tin box 2½ inches in diameter, after the manner officially prescribed, it shall not lose over 5 per cent by weight nor shall the penetration at 77° F. after such heating be less than one-half of the original penetration.

"(*d*) The solid bitumen at a penetration of 50 shall have a ductility of not less than 20 centimeters nor more than 85 centimeters at 77° F. If the penetration varies from 50 an increase of at least 2 centimeters in ductility will be required for each 5 points in penetration above 50, and a corresponding allowance will be made below 50 penetration. This test shall be made with a briquette of cross-section of one square centimeter, the material being elongated at the rate of 5 centimeters per minute. (Dow moulds.)

"Note: Combinations of asphaltic bitumens having the ductility and other characteristics above mentioned are admitted under Section 2.

"3. Refined asphalt produced by combining crude natural asphalt with either of the following:

"(*a*) Residuums obtained by the distillation of petroleum oils as specified under fluxes.

"(*b*) Asphalts obtained by the distillation of petroleum oils as specified.

"In the use of these mixtures of refined asphalts for asphaltic cement, only asphaltic or semi-asphaltic fluxes shall be used, except in those cases where the solid natural asphalt is of such

character that when mixed with paraffine flux without the addition of any other material, it will produce an asphaltic cement complying with the requirements set forth under that head. In such cases any of the fluxes elsewhere specified may be used.

"The preparation and refining of all asphalt admitted under these specifications shall be subject to such inspection at the paving plant and refineries as the (proper city official) may direct.

"*Flux.*—The fluxing material may be a paraffine, a semi-asphaltic or an asphaltic residue which shall be tested with and found suitable to the asphalts to be used.

"The residuums must have a penetration greater than 350° with a No. 2 needle at 77° F. under 50 grams weight for one second.

"All residuums shall be soluble in cold carbon tetrachloride to the extent of 99 per cent and must remain soft after heating for 5 hours at 400° F.

"(*a*) The paraffine residuum shall have a specific gravity of 0.92 to 0.94 at 77° F. It shall not flash below 350° F. when tested in the New York State Closed Oil Tester, and shall not volatilize more than 5 per cent of material when heated 5 hours at 325° F. in a tin box 2½ inches in diameter, as officially prescribed. The residue after heating shall flow at 77° F. and shall be homogeneous and shall show no coarse crystals.

"(*b*) Semi-asphaltic residuum shall have the same general characteristics as paraffine residuum except that it shall have a specific gravity of 0.94 to 0.98 at 77° F.

"(*c*) Asphaltic residuum shall have the same general characteristics as paraffine residuum except that the specific gravity shall be not less than 0.98 nor more than 1.04 at 77° F. The asphaltic residuum after evaporation at 500° F. to a solid of 50 penetration shall have a ductility of not less than 30 centimeters. (Dow Method.)

"*Asphaltic Cement.*—The asphaltic cement prepared from materials above designated shall be made up from the refined asphalt or asphalts, and the flux, where flux must be used, in such proportions as to produce an asphaltic cement of a suitable degree of penetration. The proportion of the refined asphalt comprising the cement shall in no case be less than 40 per cent by weight.

"When the weight of flux in the asphaltic cement prepared from solid natural asphalt exceeds 25 per cent thereof, asphaltic or semi-asphaltic flux shall be used.

"Refined asphalts and flux comprising the asphaltic cement shall, when required, be weighed separately in the presence of the authorized inspectors or agents of (proper city official).

"Refined asphalts and flux used in preparing the cement shall be melted together in a kettle at temperature ranging from 250° to not over 375° F. and be thoroughly agitated when hot by air, steam or mechanical appliances, until the resulting cement has become thoroughly mixed into a homogeneous mass. The agitation must be continued during the entire period of preparing the mixtures. Cement shall always be of uniform consistency, and if any portion should settle in the kettle between intervals of using the same, it must be thoroughly agitated before being drawn for use.

"(*a*) The asphaltic cements shall have a penetration of from 40 to 75, which shall be varied within these limits to adapt it to the particular asphalts used in the paving mixture and to the traffic and other conditions.

"(*b*) When 20 grams of the asphaltic cement of the penetration to be used in the paving mixture shall be heated for five (5) hours at a temperature of 325° F., in an oven as officially specified, there must not be volatilized more than 5 per cent of the bitumen present, nor shall the penetration at 77° F. after such heating be less than one-half of the original penetration.

"(*c*) A briquette of the asphaltic cement when at a penetration of 50 having a cross-section of one square centimeter shall elongate to the extent of not less than 20 centimeters nor more than 85 centimeters at 77° F. If the asphaltic cement as used in the paving mixture varies from 50 penetration, an increase of at least 2 centimeters in ductility will be required for each five (5) points in penetration above 50, and a corresponding allowance will be made below 50 penetration. (Dow Moulds.)"

The requirements for asphalt and asphaltic cement of the American Society of Municipal Improvements adopted at the Grand Rapids Meeting in 1911 were not as specific as those just given, as will be seen.

"*Refined Asphalts.*—The refined asphalts admitted under these specifications shall be prepared from any natural mineral bitumen, either solid or liquid, or from combinations thereof, by suitable and approved methods of refining.

"The preparation and refining of all asphalts admitted under these specifications shall be subject to such inspection at the paving plants and refineries as the engineer may direct and shall in all cases be conducted after the most approved manner. Every refined asphalt admitted under these specifications shall be equal in quality to the recognized standard for its particular kind or type of asphalt.

"All refined asphalts admitted under these specifications must also comply with the following requirements:

"*a.* All shipments of refined asphalt of any one kind shall be uniform in consistency and composition and shall not vary more than 15 points in penetration at 77° F.

"*b.* Ninety-eight and one-half per cent of the total bitumen of all refined asphalts shall be soluble in carbon tretachloride.

"*c.* When made into an asphalt cement by the use of such materials and methods as are described in these specifications they must produce an asphalt cement complying with all the requirements elsewhere set forth herein for asphalt cements.

"*Fluxes.*—These shall be the residues obtained by the distillation of paraffine, asphaltic or semi-asphaltic petroleums. They shall be of such character that they will combine with the asphalt to be used to form an acceptable and approved asphalt cement complying with the requirements of these specifications. All residuums must pass the following general tests:

"*a.* They must have a penetration greater than 350 with a No. 2 needle at 77° F. under 50 grams weight for 1 second.

"*b.* They shall have a specific gravity at 60° F. between 0.92 and 1.04.

"*c.* When heated for 5 hours at 325° F. in a tin box 2½ inches in diameter after the manner officially prescribed, they shall not lose more than 5 per cent by weight and the residue left after such heating shall flow at 77° F.

"*d.* They shall not flash below 350° F. when tested in a New York State Closed Oil Tester.

"*e*. They shall be soluble in carbon disulphide to the extent of not less than 99.5 per cent.

"*Asphalt Cement Requirements.*—The asphalt cement shall comply with the following requirements:

"*a*. It shall be thoroughly homogeneous and the various bituminous ingredients contained in it shall be in a state of complete solution. It shall not be oily to the touch.

"*b*. It shall have a penetration between 40 and 75 at 77° F., depending upon the sand and asphalt used and the traffic upon the street on which the pavement is to be laid.

"*c*. It shall not flash below 300° F. when tested in a New York State Closed Oil Tester.

"*d*. When heated in an open tin at a temperature of 325° F. for 5 hours in a hot-air oven, it must not show a loss by volatilization of over 5 per cent and the penetration at 77° F. of the residue left after such heating must not be less than one-half the penetration at 77° F. of the original sample before heating.

"*e*. When the pure bitumen of the asphalt cement is brought to a penetration at 77° F. of 50 and made into a briquette having a cross-section of one square centimeter, it shall have a ductility of not less than 20 centimeters at 77° F.

"Note.—When the asphalt cement as used has a penetration greater than 50 at 77° F., an increased ductility of 2 centimeters shall be required for every 5 points in penetration above 50 penetration."

The Washington specifications have no requirements for the refined asphalt, but specify as follows for the asphalt cement:

"*Asphalt Cement.*—The asphalt cement must be practically free from water, and must be within the range of 40 and 70 penetration when tested at 77° F. The amount of penetration to be fixed by the engineer commissioner.

"Preference will be given to an asphaltic cement that is not readily affected by the action of water, provided it is satisfactory in other respects. If an asphaltic cement is accepted that is affected by water, some provision satisfactory to the engineer commissioner must be made to guard against the results of such action, and such work must be included in the price bid.

"The bitumen of the asphaltic cement must comply with the following test:

"1. It must be of such a character that if when tested at 32° F. it shows a hardness of 10 penetration it must not when tested at 115° F. be softer than 350 penetration.

"2. When a briquette of the pure bitumen, having a minimum cross-section of 1 square centimeter, is tested for ductility at 77°, the bitumen must stretch 15 centimeters before breaking.

"3. When the bitumen is heated in an open tin at a temperature of 300° F. for 18 hours in a hot-air oven, it must not show a loss by volatilization of over 5 per cent and must not have been hardened over 50 per cent by this heating.

"The asphaltic cement must never be heated to a temperature that will injure it.

"When the asphaltic cement contains over 5 per cent of material that will separate by subsidence while in a molten condition, it must be thoroughly agitated before drawing from storage and while in use in the supply kettles so as to insure a uniform cement.

"These properties shall be determined by tests made by uniform methods, descriptions of which are on file in the office of the engineer commissioner."

In order to establish some standard for asphaltic cement, in 1888 Prof. Bowen, who was then chemist for the Barber Asphalt Paving Co., devised an apparatus for determining the softness, or viscosity (as chemists prefer to call it), of asphaltic cements. The object of this machine, and the principle on which the standard is based, is to determine how far a needle will penetrate the asphaltic cement at a standard temperature in a given time. The needle is weighted with a 100-gram weight and allowed to penetrate the cement for one second. The needle is inserted in the end of a weighted lever. This lever is suspended by a thread from a spindle around which it is wrapped. At one end of the spindle a pointer is fastened which indicates on a dial the distance, up or down, moved by the lever-arm to which the needle is attached. On the spindle there is a small drum, around which the thread is wound supporting the weight, which acts as a partial counterbalance to the weight of the lever. This counterweight keeps the

lever-thread tight, and when the lever-arm is raised it returns the pointer to the dial. The viscosity of the sample is determined by placing one end of the needle, which is then lowered upon its point, so as to just touch the surface of the asphalt. The position of the pointer of the dial is noted, the clamp released, and the needle allowed to penetrate into the sample for a fixed time. At the end of the time the clamp is closed and the distance the needle has penetrated can be read from the dial, which for convenience is divided into 360 equal parts, and the number of these parts which the needle has moved represents the penetration of the cement.

This is an arbitrary standard, but it has been used successfully in some twenty-five or thirty laboratories or paving-yards.

Before testing the samples, they should be kept at a standard temperature for a sufficient time to allow them to attain the desired temperature. The temperature which has been generally taken as the standard is 77° Fahr., and the simplest way to maintain the sample at the proper temperature is by immersing it in water which is kept at that temperature.

Mr. A. W. Dow, formerly Inspector of Asphalts and Cements in the District of Columbia, has adopted a somewhat different method of testing the viscosity by a machine that is somewhat complicated. His standard is the distance expressed in hundredths of a centimeter that a No. 2 needle will sink or penetrate into the asphalt paving-cement in 5 seconds when weighted with 100 grams, the cement and apparatus being at a temperature of 25° C. This makes an absolute and positive standard, but requires a delicate apparatus for the measurement. Under the Bowen standard the penetration of the asphaltic cement used in Washington by the Barber Co. in 1897 was 85, and by the Cranford Paving Co. 77; in 1898 by the Barber Paving Co. 91, and by the Cranford Paving Co. 83. In 1889, when Mr. Dow used the standard just described, the penetration of the paving-cement by the Eastern Bermudez Paving Co. was 45, and by the Cranford Co. 36, showing that in absolute figures the latter standard gives a less result than the former, but it must be remembered that the Bowen standard was wholly arbitrary, while that of Mr. Dow is absolute.

When it is remembered that only about 10 per cent of the so-called asphalt pavement is made up of bitumen, it can be readily

understood that it is necessary to select the best possible material for the remainder. Whatever this material may be, it must sustain the traffic to which the pavement is subjected. Stone in some form has been settled upon as the best material, but there has been more or less controversy always as to the size of the particles, and also as to how they should be graded. A hard material is absolutely necessary, and the particles must not be too large, else under the action of the horses' shoes the stone will pick up and leave appreciable voids in the pavement which will cause it to crumble and wear away. As has been said before, quite large stones have been used, but the experience of the last twenty years has demonstrated very satisfactorily that a hard silicious sand is the best material than can be obtained. In a paper read before the American Society of Municipal Improvements, in 1898, Mr. Dow went very carefully into the character and size of sands that should be used. He first demonstrated that asphalt cements are liquid, and basing his argument upon the fact that fine beach-sand, when wet with water, is almost solid, while the coarser sand is soft. He goes on to say:

"Looking at asphalt cement as liquid, we should expect to find analogous results when paving mixtures are made with these two sands, using with each the same asphalt cement; that the mixture made with the finer sand would be harder than that made with the coarser (this is what we find in practice), while by using a much softer asphalt cement with the finer sand and with the coarser equally hard mixtures are produced. The cause of this is explained by the fact that the voids of the finer sand are much smaller in size, which means that the sand-grains are closer together. It is a well-known fact that the smaller the space between two solid bodies that are held together by the attraction of a liquid between them, the greater the adhesion. There are two grades of sand that have small voids; one is composed of very fine grains, and the other is a sand with the grains so graded from coarse to fine that all of the large voids are filled with smaller grains and their voids in turn filled with still finer. The latter is the most desirable sand, for several reasons. Among them are: It is very easily handled in the manufacture of the pavement, and it requires less asphalt cement, not alone because the per cent of

fine is less, but the total surface area of the sand-grains is smaller."

It will be noticed in this conclusion of Mr. Dow that he argues in practically the same way as one might in relation to cement concrete, and really the principle is the same. The wearing surface of the asphalt pavement is a concrete in which the bituminous substance is the cementing matter rather than the hydraulic cement. Mr. Dow further goes on to illustrate the differences in result when different sizes of sand are used by referring to the pavement in Washington laid in 1894, which he said marked as much, if not more than, those laid in 1897, and some of the former cracked in cold weather. The asphalt cement, however, with which the 1897 pavement is laid was found to be 20° harder than that used in 1894. Consequently he inferred that the difference must be due to the sand. Upon a trial, the sand was found to be graded as follows:

TABLE No. 58.

	1894	1897.
Retained on 20 mesh per linear inch..	4.5	2.5
" 40 " " " " ..	40.0	21.0
" 60 " " " " ..	32.0	35.0
" 80 " " " " ..	9.5	8.5
" 100 " " " " ..	6.0	10.0
Passing 100 " " " " ..	8.0	24.0

He also refers to the well-known fact that the European rock pavements, the durability of which, without doubt, is greater than that of the American pavements, is made up of a limestone powder, cemented together by asphalt so soft that its flow is perceptible at a temperature of 75°, which is three times softer than any asphalt cement used at present in American pavements. It is also well known to all persons engaged in asphalt paving that the European rock asphalts are much harder on the street at the same air-temperature than the pavements in this country. He also says that angular and not rounded sand should be used, as the angular sand packs much more solidly and gives a correspondingly harder pavement. All of the sand used, of whatever sizes, should be hard and solid.

Table No. 59 shows sands used in different cities.

Table No. 59.

SHOWING SIZE OF SANDAND AMOUNT OF BITUMEN USED IN DIFFERENT CITIES IN 1911. THE FIGURES REPRESENT THE PERCENTAGE OF SAND PASSING SIEVES OFMESHES PER LINEAR INCH AS SHOWN IN FIRST COLUMN.

	Brooklyn.	Philadelphia.	Fort Wayne.	Toronto.	York, Pa.	Louisville.	Jersey City.	Chicago.	Kansas City.	Norfolk.	Boston.	Oklahoma.	Knoxville.	London, Ont.	Borough of Bronx, N. Y.
Bitumen...	10.5	10.6	10.2	9.9	10.3	11.1	11.6	10.5	10.1	10.9	10.9	10.6	11.4	10.7	10.9
200........	10.5	10.4	9.8	11.1	10.7	16.9	12.4	12.5	16.9	12.1	10.1	10.4	10.6	11.3	12.1
100........	6	14	14	18	5	18	7	10	20	11	15	9	8	8	6
80........	10	10	13	11	7	8	9	20	14	20	12	16	14	10	8
50........	42	32	28	33	32	27	36	26	20	27	24	26	45	29	39
40........	7	7	4	6	17	8	10	4	5	4	7	6	3	10	9
30........	10	10	9	8	16	13	11	8	9	12	11	13	6	14	11
20........	3	4	5	2	1	2	2	4	2	2	5	4	1	4	2
10........	1	2	6	1	1	1	1	5	3	1	5	5	1	3	2
Held on 10..	....	....	1												

Table No. 60.

SHOWING DIFFERENT SAND GRADINGS RECOMMENDED BY DIFFERENT PARTIES.

Am. Soc. Mun. Improvements.		Clifford Richardson Standard Traffic.	
		Heavy.	Light.
		Bitumen 10.5	10
Passing 200-mesh........	0– 5%	13	10
" 100- "	10–25%	13	9 } 18
" 80- "	6–20%	13	9 }
" 50- "	15–40%	24	26
" 40- "	10–30%	11	12
" 30- "	8–25%	8	10 }
" 20- "	5–15%	5	8 } 24
" 10- "	2–10%	3	6 }
" 8- "	0– 5%		

ASSOCIATION FOR STANDARDIZING PAVING SPECIFICATIONS.

	Per cent.
Bitumen soluble in cold carbon disulphide......................	9.5–15.5
Portland cement or stone dust passing a No. 200 sieve............	10.0–15.0
Sand passing a No. 80 sieve..................................	18.0–36.0
" " " No. 40 "	20.0–50.0
" " " No. 10 "	8.0–25.0
" " " No. 4 "	up to 10

The item designated as "Portland cement or stone dust passing a No. 200 sieve" within the limits named here includes in addition

to the Portland cement or stone dust fine sand passing a No. 200 sieve not exceeding 4½ per cent of the total mixture and such 200-mesh mineral dust naturally self contained in the refined asphalt.

Wearing Surface.

The wearing surface of the asphalt pavement should be absolutely impervious to water. Unless it is so, in wet weather the moisture will soak into the material and the oxygen in the water will oxidize the asphalt, changing the petrolene into an asphaltene and thus causing premature disintegration. In order to make this more certain, it has always been customary to mix with the sand a certain amount of mineral matter. As carbonate of lime was first used, it was thought that there was some chemical action between the bitumen and carbonate, and for that reason it should be used rather than any other fine material, but this idea is pretty well exploded at the present time, and paving experts generally believe that a pulverized silica is as good as, if not better than, carbonate of lime. Carbonate of lime has a tendency, especially if used in excess, to make the pavement hard and slippery, and in fact to some extent of the nature of a rock asphalt, while a silicious powder will make the resulting pavement less slippery, and in the last two or three years a great many pavements have been laid with this rather than with pulverized limestone, with invariably good results. It would have been used even more if it could have been obtained as readily and as cheaply. The wearing surface, then, of the asphalt pavement is made up of asphaltic cement, sand, and pulverized mineral matter. If these materials have all been selected and manufactured with care, the next thing to be considered is the proportion in which they should be mixed.

The powdered mineral matter should be of such degree of fineness that 16 per cent of it by weight will be an impalpable powder, and the whole of it should pass a No. 30 screen. The exact quantity to be used must be determined by the gradation of the sand, as the object of the mineral matter is to fill the voids in the sand so as to make the total voids as small as possible. The amount generally used is from 4 to 8 per cent. The amount of paving-cement required depends, first, upon the character of the cement, and, second, upon the voids in the combined sand and mineral powder.

Refined Trinidad asphalt contains about 55 per cent bitumen,

refined Alcatraz about 80 per cent, and refined Bermudez about 95 per cent. So that whatever the nature of the fluxes by which asphaltic cement is made from either of these asphalts, the resultiug cement must vary greatly in the amount of bitumen contained if the same amount of asphalt is used. It is admitted at the present time that the wearing surface should contain, speaking generally, from 10 to 12 per cent of bitumen, and at all events not less than $9\frac{1}{2}$ per cent, although in some exceptional cases good pavements have been in existence for some years where the analysis showed not more than 7 per cent bitumen. Consequently, in order to obtain $9\frac{1}{2}$ per cent of bitumen in any mixture, more Trinidad cement will be required than Alcatraz, and more Alcatraz than Bermudez. One asphalt company in giving directions for the determining of the actual amount of asphaltic cement says: "Take the known weight of the sand and powdered carbonate of lime, previously deprived of water and thoroughly mixed in the proportions determined upon. Place same in a large tin or iron bucket; add water until no more can be absorbed and until the voids are all filled with water, and no more. The resulting increase in weight will of course give the weight of water necessary to fill the voids of so many pounds of sand and powdered limestone. Multiply the weight of the water thus obtained by the specific gravity of the asphalt, and the result will be the least amount by weight of asphalt cement required to fill the voids of the known weight of sand and mineral matter." In illustrating this they say: "Let us suppose, for example, that 50 lbs. of sand and 6 lbs. of powdered limestone were found to absorb $5^1/_2$ lbs. of water. In that case, since $5^1/_2$ times $1^1/_{10}$ (the specific gravity of that particular asphalt) equals $6^5/_{100}$, the resulting mixture should be:

	50	lbs. sand
	6	lbs. carbonate of lime
	$6^5/_{100}$	lbs. asphaltic cement
Total,	$62^5/_{100}$	lbs.

Or, reducing these figures to a percentage basis, we have practically:

80	parts by weight of sand
10	parts by weight of carbonate of lime
10	parts by weight of asphalt cement
100"	

Thickness of the Wearing Surface.

After determining upon the composition of the wearing surface, it will next be proper to decide upon its thickness. A certain amount of the paving material, of whatever kind, must always be wasted when a pavement is relaid. It is never possible to get the entire amount of wear out of the whole surface, so it is not economy to lay a greater thickness than can be used to advantage. If the thickness of the wearing surface be too great, it will not be possible to give it proper compression under the roller, and consequently the entire amount of material will not be used, and in fact the pavement will be more likely to fail than if the portion actually compressed was laid upon a solid base rather than the softer asphalt which was not compressed. In actual practice it has been found that a compressed asphalt of 2 inches gives the best satisfaction. This requires the material to be spread loosely, as it is brought upon the street, to a depth of about 2½ inches. In light-traffic streets the surface is sometimes made 1½ inches thick, but, on the principle laid down above as to the economical wear of the entire amount laid, it would seem that, even if the travel be light, it would be true economy to lay a pavement of such thickness as could be thoroughly compressed. Methods and proportions for mixing will be discussed later on.

Binder.

The first asphalt pavements were laid 2½ inches thick, with a so-called ½-inch cushion-coat laid first and rolled upon the concrete, and a top coat 2 inches thick laid upon that. If the concrete contained any appreciable amount of moisture when the hot cushion-coat was laid upon it, the moisture was evaporated into steam and bubbles formed, raising the cushion-coat in small places from the concrete. It was also found that it would be difficult to prevent the cushion-coat from sliding on the base and at the same time to get a thorough bond between the top and the cushion-coat, so that it was deemed best to change somewhat the method of construction, and for the cushion-coat to substitute a so-called binder, made up of coarse stones held together by asphaltic cement. This binder has been laid of different thicknesses, sometimes 1½ or even 2 inches. Its object, however, is simply to serve as a medium between the

wearing surface and the concrete. The binder will take a firmer hold upon the concrete than the finer top surface would, and the top surface will form a perfect union with the binder, so that in this way a better result is obtained than by the old method. As the province of the binder is simply to serve as this connecting link, there seems to be no necessity for making it any thicker than what is required to make a solid course, and the thickness of 1 inch seems ample for this purpose.

The Committee on Asphalt Pavements of the American Society of Municipal Improvements in its report provides that binder stone shall be clean, hard stone, free from any particles that have been weathered or are soft, and that it shall pass a 1¼-inch screen; not less than 85 per cent of the stone shall pass this screen in its largest dimension, and of the remaining 15 per cent no piece shall have a larger dimension than 2 inches; the stone to be so graded from coarse to fine as to have the following mesh composition:

Passing 10-mesh 15 to 35%	Total, 25 to 50%	Total passing 1-mesh 45 to 85%
" 2-mesh 10 to 35%		
" 1-mesh 20 to 60%	Total, 50 to 75%	
" 1¼-mesh 15 to 55%		

The binder stone is cemented together by asphaltic cement. It is not always necessary that voids should be filled, but enough cement should be used to insure the stability of the mixture.

When a binder was first used it was thought better not to have the voids of the stone filled, and this practice is in use now on streets of light traffic. Experience, however, has developed the fact that on heavy traffic streets the wearing surface is pounded into the unfilled voids of the binder stone, often producing depressions in the pavement sufficient to hold water, which tends to soften the pavement, and the depressions also produce unequal wear, so that the results are not satisfactory. To overcome this difficulty what is known as the close binder is used upon heavy traffic streets. This is produced by mixing stone dust with the asphaltic cement, and sometimes sand, so that a mixture somewhat like the wearing surface is obtained, which fills the voids in the binder stone and is able to sustain the traffic. When this close

binder is used it should be laid an inch and a half thick to insure a good body.

The specifications for close binder in the Borough of Manhattan, New York City, say:

"The binder stone and sand, as above specified, shall be heated to from 200° to 325° F. in suitable appliances. Stone and sand shall be measured off separately and then be mixed, with sufficient asphaltic cement, prepared as heretofore specified, in such proportions that the resulting aggregate will contain by weight material passing a 10-mesh screen, between 25 and 35 per cent, and bitumen in quantity from 5 to 8 per cent of the entire mixture. Binder thus prepared shall be a compact mass containing a minimum of voids."

Foundation.

Of whatever material the asphalt pavement may be made, or with whatever care it may be laid, it will always be a failure unless it is laid on a good foundation. This statement is true of almost every work of construction, but it is particularly so of asphalt, because the asphalt itself simply acts as a carpet to receive the traffic, but the weight must be borne by the foundation. Asphalt has no inherent strength. It does its work by its elasticity, simply transferring the loads to the foundation.

Mention has been made of a bituminous base used in the early days in Washington. In South Omaha, Neb., in 1891 an asphalt pavement was laid on a bituminous base somewhat differently constructed than those of Washington. It was made of broken stone and gravel 6 inches deep, and the entire portion thoroughly mixed with asphalt so that the base itself was a concrete cemented by asphalt. Upon a good foundation this makes a good base, but it has not much strength in itself, and when the pavement comes to be relaid it is generally necessary to take up the entire base. The best base is made of broken stone and hydraulic cement concrete. Its thickness depends upon the traffic of the street, but it is almost invariably laid with a depth of 6 inches. Some time after the success of asphalt pavement was fully assured, an attempt was made to reduce its cost and allow it to compete more successfully with

other pavements by varying its character and thickness according to the amount of traffic. A foundation of 6 inches of broken stone was laid upon a prepared subgrade and thoroughly rolled. Upon this was scattered coal-tar in quantity approximating 1 gallon per square yard. The asphalt was then laid upon the stone. This base is even more objectionable than the one spoken of in South Omaha, as it has absolutely no strength in itself, will settle with every inequality of the ground upon which it rests, and unless the subgrade has been made absolutely solid and compact, the surface of the pavement must become rough and uneven. With proper care, however, in preparing the subgrade and by rolling the broken stone in somewhat the same manner as is done for macadam pavements, a foundation can be obtained which, if not disturbed by plumbers or for any subsurface construction, will give good and satisfactory results, but its cost in that case would be almost as great as if laid with hydraulic cement.

In 1899 such a base was being used in some instances in Philadelphia, but probably not in any other city in the country to any extent.

When an old stone pavement is being replaced with asphalt, it is often desirable to lay the new pavement over the old and thus save the cost of a new foundation. This has been done to quite an extent in many cities. Notably so in New York and Brooklyn. Many of the old cobblestone streets in Brooklyn have been covered with asphalt. There would be almost no objection to this practice if the street were to remain undisturbed by plumbers, and the old pavement were laid with the proper cross-section desired for the new, but in almost every case it is necessary to relay at least one-half and sometimes the whole of the old cobblestone in order to get the desired cross-section. This gives a foundation which must necessarily be more or less unstable, and when the entire surface is relaid the cost would be fully one-half that of the hydraulic-cement-concrete foundation. There are also a great many holes and inequalities in a cobblestone pavement which must be filled up or repaved. In such a case, where the old cross-section will admit, a most satisfactory result can be obtained by filling in all of the inequalities with broken stone and rolling them to a true surface across the entire street and laying the pavement upon it. Asphalt

has also been laid quite successfully over granite and Belgian block pavements. There has been a great amount of this work done in New York City. There the pavements in almost every instance were taken up and relaid at a lower elevation than originally, so as to bring the surface of the new pavement approximately equal to that of the old. When this is done the blocks are laid with quite open joints, filled to within about 1 inch of the top with sand, leaving room for the binder to fill up the remainder and so obtain a firm hold upon the new surface. Asphalt has also been laid over old macadam roads, and where the pavement is to be undisturbed no possible objection can be made to this practice.

Laying the Pavement.

With good materials, well mixed, and in proper proportion, it is very easy to produce a poor pavement by bad manipulation and inexperienced workmen on the street. After the foundation, of whatever nature, is ready for the pavement proper, the binder should be brought to the street and spread to such a depth (which can easily be determined by practice) as will give it a thickness of 1 inch after being compressed. If the foundation is cement concrete, and has not had sufficient time to become thoroughly set, it should be covered on one side with planks for the trucks to drive over, especially if the blocks are long. It is also often better, when the blocks are of extreme length, to begin laying the binder in the centre rather than at one end, so that the trucks will not be obliged to drive over the foundation for more than half the length of the block, thus saving, if the planks are used, half the amount of material and preventing any damage to the foundation. The same rule will hold good in laying the top, as, however good the binder may be, it is liable to be injured by too much driving if the blocks are of extreme length. The laying of the wearing surface should follow the binder as quickly as possible. Should the weather be good, this is not so essential; but in wet weather, or in the latter part of the season, the binder, being porous, is liable to be acted upon by the moisture and become brittle and disintegrate under a small amount of traffic if it has remained exposed for any appreciable length of time. In such weather, where possible, it is good

practice to lay the binder in the forenoon and cover it with asphalt in the afternoon, although if the following day should be pleasant this would not be actually necessary.

In preparing for the wearing surface, a line should be marked along the curb at the height of the finished surface, so that it can always be ascertained whether a sufficient depth is obtained. The surface of the concrete having been laid in the same manner as that described for stone pavements, by means of ordinates, the thickness of the asphalt at any point on the street can be determined by stretching a line from curb to curb and measuring down at any desired point.

The material for the wearing surface should be brought upon the street, in carts protected from the weather, at a temperature of not less than 250°; and if the weather be cold, 275° or even 300° is preferable. After being dumped upon the binder it is spread out into its approximate depth by shovellers, and then graded off by experienced workmen with rakes. Several devices have been used for determining the proper depth of the loose material, such as having rakes with teeth of a certain length, etc., but after a little experience, an intelligent laborer soon learns the required depth, and easily tells by his eye whether or not a particular place is too high or too low. As soon as the material is spread out to the required depth by the rakers, it should receive its preliminary compression by hand-rollers, after which hydraulic cement should be lightly broomed over the surface and then rolled by a steam-roller weighing about five tons. This roller should be followed in a short time by one weighing not less than ten tons, or 250 lbs. per inch of roller. The object of the three rollers is to allow the asphalt to be compressed without being pushed forward. If a heavy roller is used at first, before the material has had the preliminary compression, the tendency will be in many cases to push the material at times rather than compress it vertically, and thus cause inequalities in the surface which are very hard to be rolled out. This rolling should follow the distribution of the material closely, so that it shall not have time to cool before the final compression is obtained. Some asphalts have a certain amount of natural set in themselves, and consequently require more care in rolling than others; for if this set takes place before the final

compression is reached, no amount of rolling will produce a true and impervious surface. The state of the weather also is an element to be considered. If a strong wind be blowing, the material, spread out as it is, over a broad surface only 2 or 3 inches thick, will cool much more rapidly than on a calm day when the temperature is considerably lower. On the other hand, when the weather is hot there is no necessity of following up the rakers so closely. The rolling should be continued without any cessation until the asphalt has received its ultimate compression. If the street be wide enough, the rolling should be done crosswise as well as lengthwise on the street, and in any event the rolling should be done at as great an angle as possible, so that any little inequality which might be caused by the roller moving lengthwise may be taken out by this cross-action. The amount of rolling required depends upon circumstances greatly, but in general two such rollers as above described should roll 2000 square yards of wearing surface in ten hours. Fig. 17 represents the cross-section of an asphalt pavement.

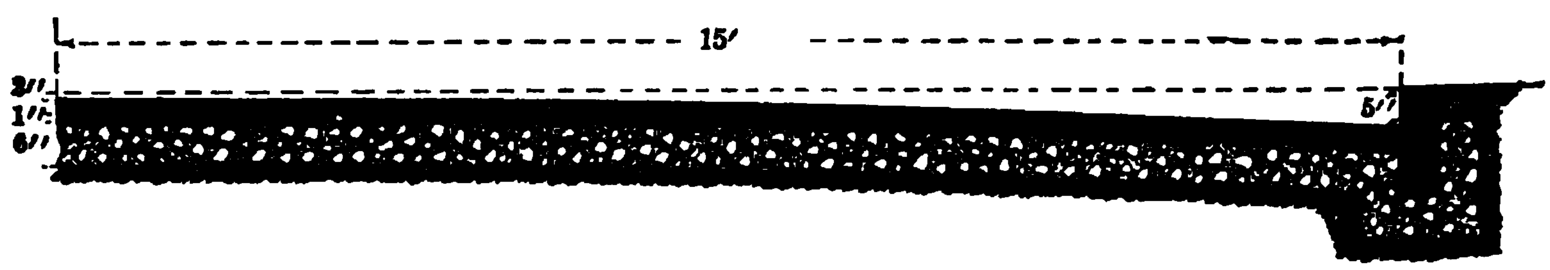


FIG. 17.

When the mixture for the wearing surface is dumped upon the binder all lumps should be carefully broken up and spread out, and the material taken up clean from where it was dumped upon the binder, lest if any appreciable amount be left it will cool and become hard before it is covered up by the top, and so not receive the required amount of compression, and eventually wear away and fail at this place.

In making the connection with the pavement that has been laid at any appreciable time before, care should be exercised to make a perfect joint with the old work by heating the edge or painting it with asphaltic cement. In some asphalts it is necessary to cut the joint down vertically; otherwise if it is chamfered off, it will afterwards scale under traffic.

Where asphalt pavement joins a street-car track, stone header, or any unyielding surface, it should be laid about one-eighth of an

inch above it, as wheels coming from the hard iron or stone to the softer asphalt will compress the latter, so that soon a depression will be formed, eventually becoming a hole under the blows from the wheels.

Gutters.

In most cities it is customary to lay the asphalt up to the curb. In such cases special care should be exercised to thoroughly compress the material in the gutter; and as it is often difficult to roll this thoroughly, it should be tamped by hand with irons especially prepared for this purpose. A straight-edge some 12 or 14 feet long should be used, so that the gutter may conform to the exact grade of the curb and be free from any slight depression. For a distance of 12 inches from the curb the surface should be painted with asphaltic cement and ironed in with hot smoothing-irons. This should be done immediately after the tamping, before any foreign matter has gathered upon it and when the pores are comparatively open. The object of this is to saturate the material thoroughly with asphalt and prevent any subsequent absorption of moisture which would lead to disintegration. The smoothing-irons used should not be too hot. Iron does not show any heat by color until it is at a temperature of about 1000° or 1200° Fahr., and this temperature would be detrimental to the asphalt and liable to burn it sufficiently to cause disintegration.

It is claimed by advocates of Bermudez and Alcatraz asphalts that the water does not injure either material, and for that reason this work is not necessary; but at the present time it is customary to treat all asphalts in this manner where the material is laid from curb to curb. On account of this effect of the water, however, stone, brick, and sometimes cement are used for gutters in some cities. In the city of Washington the officials have decided to use vitrified paving-brick for this purpose. This material has been in use there for some years, and has given satisfaction, as it presents a smooth surface to traffic and is not acted upon by the water. Where either stone or brick is used, the concrete should be depressed sufficiently so that there shall be the same amount under the gutter as under the pavement proper, and the blocks should be set in mortar on the concrete, not on the cushion of sand, so that they

shall be perfectly rigid, and the joints poured either with Portland-cement grout or asphaltic cement.

Temperature for Laying.

It has long been a mooted question at what temperatures the laying of sheet asphalt should be discontinued. Where it is not definitely stated in specifications, it is generally stipulated that it shall cease at a temperature below freezing, but this is very seldom done in actual practice. It is certain that better results can be obtained by laying the asphalt in warm weather than in cold, as a more perfect and even compression can be obtained. That this is important was demonstrated on a street where the work was completed at a low temperature and opened for traffic. It soon began to pick up under the impact of the horses' feet, and quite a portion of it had to be repaired, and at one time it looked as if an entire block would require relaying. Eventually the weather grew warm again, and in a few days the action of the traffic had obliterated all signs of the picking up, and the compression required was obtained by travel, and no further trouble occurred from that source.

In another instance, a street containing some 12,000 yards was surfaced at a temperature of about zero where the haul from the plant was about 1½ miles. Nearly half of the work was performed under these conditions. The street picked up considerably under travel during the winter, and the indications were that quite a portion of it would require to be resurfaced in the spring; but fortunately there was only slight travel on the street during the winter-time, so that not much damage was done, and the traffic during the coming summer put the street in such a condition that only about $500 was expended upon it during the guarantee period of five years. The practice of doing work under these conditions, however, is not to be commended, as it is in exceptional cases only that good results are obtained.

In order to be sure of good work, the wearing surface should not be laid at a temperature below 20°.

Cracks.

One of the principal ways in which asphalt pavement has failed in cities subjected to great extremes of temperature is by the form-

ing of cracks. These are thought by some engineers to be caused by the pavement cracking through the base, but a careful study of the subject does not seem to bear out this view. In one instance a pavement laid in one of the Southern cities was subjected soon after completion to a rapid change of temperature of about 40°, but even then it was but little below the freezing-point, and not enough to cause any contraction in the concrete base, but the asphalt surface showed a great many fine cracks, demonstrating conclusively that these cracks were formed in that particular instance, at any rate, by the contraction of the wearing surface itself.

Many specifications in detailing how the wearing surface should be laid say that the material shall be such as to form a pavement which shall not be too soft in the summer, nor crack and disintegrate in the winter. This is a simple proposition in the specifications, but not so easy to carry out. The engineer generally wishes a pavement to be laid as hard as possible without cracking. The contractor, on the other hand, has as his standard one that will be as soft as possible and not mark or rut too much in hot weather. It is well known that a pavement hardens as the volatile oils evaporate and the asphalt becomes oxidized, so that the softer the pavement is laid the longer it will probably last, and the aim of the contractor is to lay it as soft as possible without bad results the first season. Very frequently complaints are made of new pavements cutting up and becoming rough under the action of travel when laid in hot weather, which after the first summer give no trouble whatever. As material is laid soft and in hot weather, allowance must be made for the changing temperature to come, and to meet this successfully the skill of the contractor is taxed. A pavement that is laid soft will seldom give trouble by cracking except after it has been laid a long time. In Western and Northern cities, where the range of temperature is great, it is probably impossible to lay sheet-asphalt pavements that will not crack in extremely cold weather. In the vicinity of New York City very little trouble is experienced by cracking. In some cities engineers have sought to remedy this trouble by making an expansion-joint crosswise of the street at frequent intervals. The theory of the expansion-joint in any structure is that the material is free to slide upon the base upon which it rests. This is certainly not true of a well-constructed

asphalt pavement, as it is hardly conceivable that a binder with this superimposed pavement could slide any appreciable distance on the concrete. An expansion-joint will certainly cause a crack to form, wherever it is made, at a change in temperature, while really the contraction of the material might be entirely taken up by the elasticity of the asphalt. At all events, the most that it could accomplish would be the formation of the cracks at regular intervals, which is neither desirable nor of any particular advantage.

These cracks form sometimes from the centre towards the gutter and sometimes from the gutter towards the centre, but always in the line of the least resistance. As the pavement becomes older more cracks appear diagonally and lengthwise of the street, dividing the pavement into irregular areas. When these become small and the cracks large the pavement must be relaid. These cracks often appear in a pavement without doing any particular amount of damage, especially if there is considerable traffic on the street. If, however, there is not traffic enough to consolidate the pavement after the weather becomes warm, the moisture enters the cracks and hastens disintegration. The best method of taking care of the cracks is to prevent them, or where not possible to do that entirely, to devise, by a study of the conditions, a composition that will withstand changes of temperature to the best advantage.

If a pavement is laid too soft and the traffic is heavy, the result is that an uneven surface soon forms, the top pushes under traffic, either upon itself or upon the binder, or the whole upon the concrete, and holes appear long before they should in such cases, and the soft surface must be taken up and relaid with harder material. This trouble may be caused by too much flux in the asphalt cement, or by an excess of bitumen being used in the wearing surface.

Effect of Illuminating-gas.

The action of illuminating gas, as it sometimes escapes from leaky mains, is very detrimental to asphalt pavements. Pavements have failed in many instances from causes for which no explanation could be given at first, and the surface was relaid without any question; but in one instance the pavement failed so frequently

that a careful examination was made and the odor of gas detected, and when the asphalt was all taken up sufficient gas was found to give a perceptible flame when lighted, although the base was 6 inches of cement concrete. An examination of the gas-main at this point disclosed a large leak. In other cases also when this failure has been noticed broken gas-mains have been discovered.

The action of gas is generally made manifest by the appearance of a great many cracks or checks in the pavement, lengthwise of the street, which under traffic soon become soft and the pavement disintegrates. Whether the gas companies shall make such failure good, whether they shall be repaired by the contractor who has the pavement under guarantee, or whether the expense shall be borne entirely by the city, is an interesting problem, but one which has not been satisfactorily solved at the present time.

Damage by Fires.

Another cause of damage to asphalt pavements is the building of fires upon them. While this should never happen, as a matter of fact it does, and from the report of the water-purveyor of New York City it is seen that during the year 1896 alone 8654 square yards of asphalt were destroyed by fire, at an expense to the city of over $30,000. In 1894 the asphalt so destroyed amounted to 3410 square yards, and in 1895 to 3692 square yards. The probable reason for the excess in 1896 was the fact that it was a presidential year, and the youth of New York consider it proper to celebrate the victory by building bonfires upon the pavement, without regard to its effect.

In later years in the Borough of Manhattan the cost has been·

1908	$29,083.00
1909	16,482.00
1910	13,400.00
1911	8,609.00

It must be understood that this means the cost of repairing damages done by fire to pavements under guarantee, as the cost of streets out of guarantee is included in the general cost of repairs. The reduction in cost has undoubtedly been brought about both

by the reduction in the amount of pavement under guarantee and because more care is used in preventing fires.

Standard for Condition of Street at End of Guarantee Period.

In the early contracts for asphalt pavements there was inserted a clause requiring the streets to be kept in good repair for a term of years, and turned over to the city in such condition at the end of the specified time. The words "good repair" are indefinite, liable to mean one thing to the engineer and something else to to the contractor. So much controversy has arisen over this point that present specifications attempt to make clear what is expected and required.

At the meeting of the American Society of Municipal Improvements, held in Grand Rapids, Mich., in 1911, this point was reported upon by a sub-committee on asphalt pavements and discussed at considerable length by the engineers present, and after the discussion the following was determined upon as the proper requirement:

"*Condition at Expiration of Guarantee.*—In addition to the proper maintenance of the pavement during the period of guarantee, the contractor shall, at his own expense, just before the expiration of the guarantee period, make such repairs as may be necessary to produce a pavement which shall:

"*a.* Have a contour free from depressions of any kind exceeding $\frac{3}{8}$ of an inch in depth as measured between any two points 4 feet apart on a line conforming substantially to the original contour of the street.

"*b.* Be free from cracks showing disintegration of the surface mixture.

"*c* Contain no disintegrated surface mixture.

"*d.* Not have been reduced in thickness more than $\frac{3}{8}$ of an inch in any part.

"*e.* Have a foundation free from such cracks or defects as will cause disintegration or settling of the pavement or impair its usefulness as a roadway."

Rock Asphalt.

The rock asphalts of Europe have been made entirely of bituminous limestone. Generally the stone had become impregnated in some manner with bitumen so that it became almost one substance. Some bituminous limestone has been found in this country, as well as a sandstone bearing asphalt, and also in California beds of sand which contained asphalt, and of which many of the early California asphalt pavements were made. These pavements were laid in a very crude manner, with but little knowledge of the material or the subject, and a great many of them failed in a short time, as might have been expected. These failures, however, should not have been charged up to California asphalt or to asphalt pavements, as experience has demonstrated that with the proper treatment a good pavement can be laid of this material.

Buffalo, N. Y., probably has laid more rock asphalt pavement than any other city in the United States; some of it has been laid with imported foreign asphalt, and quite a large amount by a combination of the foreign with the Kentucky rock asphalt. The first Kentucky rock pavement was laid in Buffalo in 1890 as a sample, since which time nearly 10 miles have been laid. Successful pavements have been laid with an asphaltic sand rock of Indian Territory, although they have not been developed to such an extent as the Kentucky asphalt.

Method of Laying.

The method of laying the European rock asphalt is entirely different from that of the ordinary sheet asphalt. The material is taken from the mines and shipped to the city where it is to be used in its natural state. The products of the foreign mines vary in the amount of bitumen contained, some having too little and others too much, so that it is generally necessary to mix the different products so as to get the required amount of bitumen in the pavement, which is approximately 10 per cent.

After these proportions have been determined and the material mixed, it is first crushed with rollers at the plant and then reduced to a fine powder by being passed through disintegrators, after which it is sifted through a sieve to separate any lumps that might otherwise get into the pavement. This powder is then heated in

a cylinder which is kept constantly in motion to allow the air to circulate freely among the particles, and kept for about two hours at a temperature from 300° to 325° Fahr. The material is then carried in carts to the street and spread upon the prepared base to a depth that will give the required thickness when thoroughly compacted.

The binder course is not generally used with rock asphalt, although it is sometimes. Over the powder spread upon the street a light roller is run to give the surface its initial compression, when workmen, each with a round iron rammer some 6 or 7 inches in diameter, carefully go over the surface, one following the other, all striking blows, in unison, on the asphalt until it is thoroughly compacted. A coat of hydraulic cement is then spread over the surface, when it is ready for the final rolling, which should be done by steam, and preferably with an arrangement inside the roller for keeping it hot. About twelve hours after the rolling is completed and the material has become cold, the street can be thrown open to travel, which continually adds to the compression already given. It has been found in several instances, where a pavement has been laid and subjected to heavy traffic for a number of years, that while it has decreased very materially in thickness, its weight has not correspondingly decreased, showing that compression has been continually going on. Rock asphalt very seldom gives any trouble by cracking.

In a report upon rock asphalt pavements made to the corporation in 1900, the City Engineer of London names sixteen streets that were relaid at the end of the guarantee period. The original contract provided for free maintenance for two years and a specified sum for the fifteen years next following, making a total life of seventeen years. The following streets lasted longer:

	Years.
The Poultry	19
London-Wall	20
Princess Street	22
Lothbury	23
Mansion House Street	28

The cost of maintaining these streets after the first two years was from 12½ to 37½ cents per yard per year, the average being 20 cents. To quote from his report:

"In nearly all of the main streets of the city which have been paved with compressed asphalt, it has remained down during the contract term without an entire relay, and in some instances, in minor streets with small traffic where the contract term of maintenance has been extended, the pavements have been down for nearly thirty years."

Repairs and Maintenance.

It is extremely difficult to ascertain just what the expense has been to different municipalities for keeping in repair their asphalt pavements. First, because these pavements are laid with the condition that the contractor guarantees them and keeps them in repair for a period of at least five years and sometimes ten and even fifteen years. This practice arose from the hesitation of all cities to adopt an untried material like asphalt for street pavement without a guarantee that they should be freed from any cost of repairs for at least that time. Consequently it is impossible to get any information of the repairs for the first five years.

Second, because the proper method of taking care of the streets after the guarantee period had expired is a question of great importance to all cities which had adopted this pavement, and has not yet been definitely determined. The asphalt industry was in the hands of a few people, and they only were capable of undertaking any repairs. The plan adopted by Omaha, Neb., in 1888, when the first pavement laid there reached the end of the guarantee period, was to make a contract with the paving company to keep all of the pavement thus laid in repair for an additional ten years for 8 cents per yard per annum for the entire area of the pavement, no matter how much was actually relaid. While this gives the exact cost to the city, it does not give any indication of what the actual expense was to the contractors. At that time no asphalt pavement had been laid fifteen years in this country, and no one could tell what its condition would be at the end of that time, so that any figures as to the cost of the repairs of the same could be nothing but a guess. Without doubt on certain of the heavy-traffic streets of Omaha the expense for repairs for that period was more than the sum received; but on others, where the traffic was less, the cost of repairs was correspondingly less.

The objection to this method is that, no matter how well the pavement may be laid, or how little travel there may be, it will cost just as much for repairs as the pavement on a heavy-traffic street. Its advantage is an exact knowledge of what the pavement will cost for a specified term of years.

In Buffalo, according to report of the Engineering Department for the year ending Jnue 30, 1910, repairs were made and paid for according to the unit prices of material and the labor per square yard, the cost being:

	Contract Price.	Average Quantity per Square Yard.	Cost.
Asphalt surface mixture per cubic foot..	$0.38½	1.395	$0.536
Binder (open) per cubic foot...........	.17	.868	.148
Asphaltic cement per gallon...........	.18	.072	.013
Labor per square yard................	.33	....	.330
Total........................	....	....	$1.027

It is stated in the report that these prices carry a guarantee for 1 year, and that ordinarily that guarantee costs about 2 cents per yard, so that the price as worked out is practically $1.00 per square yard.

The cost of repairs in Buffalo have been kept in much detail for many years, and the average cost of maintaining 43,000,000 yards out of guarantee has been 3.78 cents. The engineers estimate the life at 20 years, and consider that to keep the pavements in good repair it will cost 4.5 cents per yard after the expiration of the guarantee in order to obtain this life of 20 years, the guarantee in Buffalo at the present time being for ten years.

Tables are given in the report of the life of different pavements, in which it is shown that the streets without car tracks have a life varying from 1.76 to 2.82 years longer than those with tracks, and on a number of streets paved in one year, with and without car tracks, the streets without car tracks had lasted 2.28 years longer than those with tracks.

In Washington practically the same system is employed as that of Buffalo, except that the price per cubic foot covers all

material as well as labor of laying. The prices in Washington for the final year of 1911 for repairs are, for laying a standard asphalt surface, 60 cents per square yard, measured on the street, or 44 cents per cubic foot measured in the car; for asphalt binder 25 cents per cubic foot measured in the car. The Washington authorities give the average life of an asphalt pavement in that city as 20 years.

In Toronto, Can., where repairs are made with a municipal plant, the work costs 77 cents per square yard of pavement actually laid.

In Brooklyn, where repairs are and have been made for some years with a municipal plant, the work in 1911 cost, for street-car streets 6.5 cents per yard and for streets without car tracks, 2.9 cents per yard; and the average of all streets was 3.4 cents per yard. The average of all streets for the last 5 years was 3.68 cents per square yard.

The cost in Brooklyn for maintaining 18,000,000 square yards has averaged 3.9 cents per yard. In Rochester the cost in 1907 was 6.8 cents per square yard, and for 1911 9.17 cents per square yard.

These four places, Rochester, Washington, Buffalo and Brooklyn, have kept their costs of repairs in better shape than any other cities, and for that reason their results should be of value.

The City of Detroit has maintained a municipal plant for 8 years, and in a circular recently issued it gives the cost of city and private patching during that time as $1.06 per square yard for work actually laid.

Attempts have been made by a number of people interested in the subject to determine the life of asphalt pavements by the cost of repairs, and it would seem as if this were the logical way to determine it; but the results obtained are so inconsistent in this respect that is seems almost impossible to draw legitimate conclusions. So many conditions affect the life of an asphalt pavement, such as traffic, the liability of bad workmanship and of poor materials, as well as the digging up of the street or possible action of gas, that the streets do not seem to cost more for repairs according to their age. Fig. 18 is a diagram showing the cost of repairs to pavements in Brooklyn, Buffalo, Washington, and

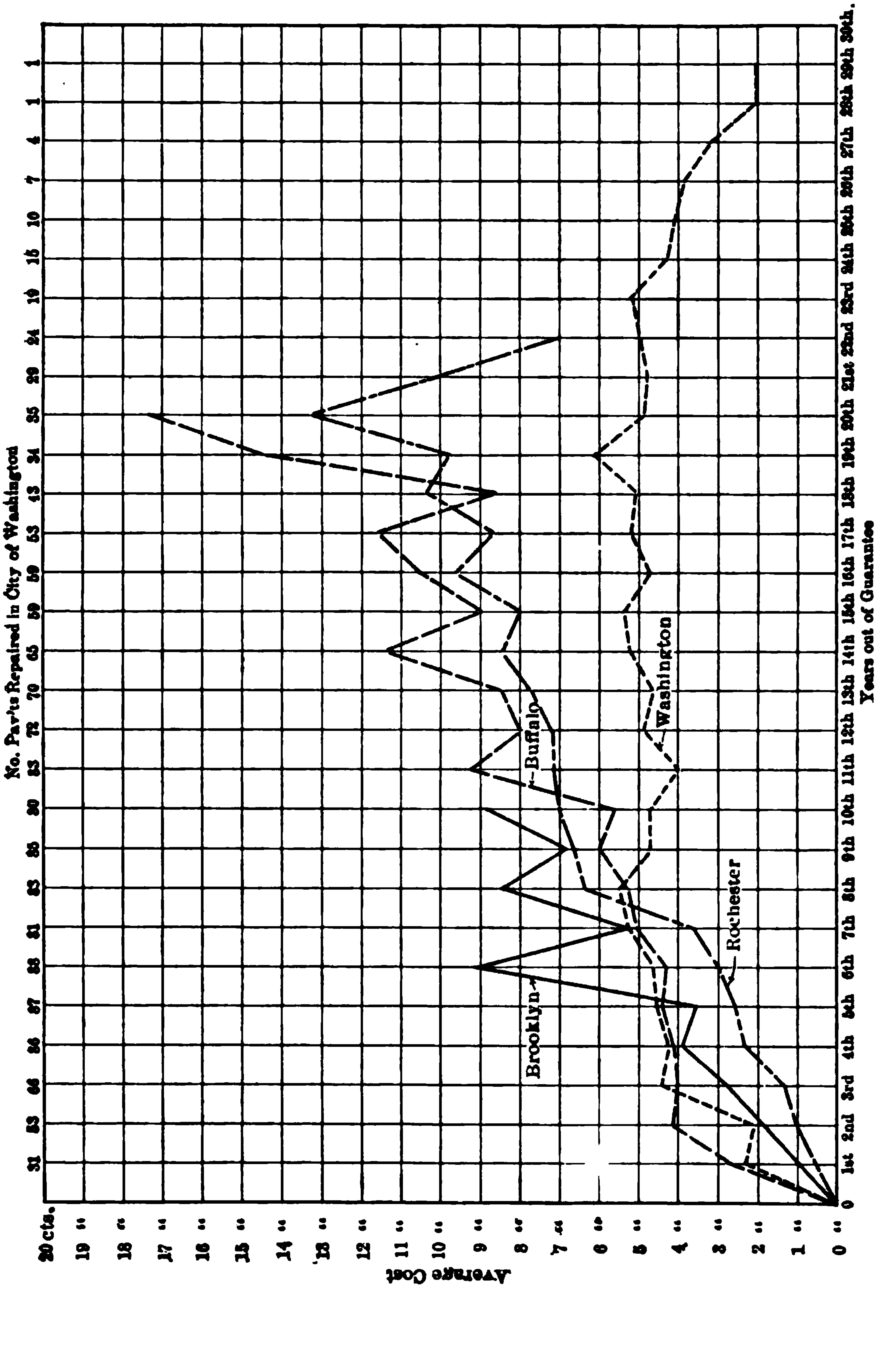


FIG. 18.—Diagram showing average cost per square yard for maintenance of all pavements in the Borough of Brooklyn, City of New York, City of Buffalo, City of Washington, D. C., and Rochester.

Rochester for each year out of guarantee, the guarantee being 5 years in each case. For Brooklyn the costs are only given for 10 years as records have been systematically kept only for that length of time. The costs in Buffalo are given for 20 years and for Washington 29 years, the upper figures of the diagram giving the number of streets that have been used in making up the Washington costs. The figures for Brooklyn, Buffalo, and Rochester are fairly consistent, but the remarkable part of the Washington line is that the cost never exceeds 6 cents per yard per year, and that is not reached until the nineteenth year, when the cost decreases until it becomes 2 cents for the twenty-eighth and twenty-ninth years out of guarantee. For these last 2 years, however, only one street is considered, so that these figures are not so valuable; but for the twenty-fifth year, for instance, 7 streets were taken, and the cost per yard per year was less than 4 cents. Despite the fact that the streets of Washington are wide, the traffic light, and the work that has been done unquestionably good, the result is certainly remarkable.

In the Borough of Manhattan, New York City, in 1911, 140,995 square yards of asphalt were relaid which had an average life of 13.8 years. The cost of keeping these in repair for the last 3 years had been 26.9 cents in 1908, 22 cents in 1909, and 34 cents in 1910. The average age of the streets resurfaced in 1912 was 14.2 years, and the cost of keeping them in repair had been 17.7 cents in 1908, 14.2 cents 1909, 16 cents in 1910, and 38.5 cents in 1911. These pavements were originally practically all laid on old stone foundation, and probably no greater extremes in conditions governing the use of asphalt could be found than in the Borough of Manhattan and the City of Washington.

Reference has often been made to the difference in the character of the European and American asphalts, and it has always been considered that the European or rock asphalt is more durable than the American output, and it probably is. The Borough of Brooklyn has four streets paved with European rock asphalt, three of which have been laid 15 years and one 16 years. The one that is 16 years old has cost 2.3 cents per year for the 11 years out of guarantee, while the others have cost, respectively, 5.4

cents, 1.2 cents, and 6.6 mills per year for the 10years out of guarantee.

According to the records of the Bureau of Highways, Borough of Brooklyn, there were twenty-six different streets out of guarantee 8 years where the average cost per yard per year had been less than 1 cent. On five of them no money at all had been expended. The average cost per yard per year out of guarantee for the twenty-six was 3.4 mills.

It may be of interest to give a brief history of what is probably the oldest asphalt pavement in the country. This is in Washington, on Vermont avenue, between H and I streets. It comprises 4100 yards and was laid in 1880 over an old bituminous-concrete pavement, in which coal tar pitch was used in the binder for the bottom course and a combination of coal tar pitch and asphalt for the top course, the original pavement having been laid in 1869. The cost of repairs on this present pavement, which in 1912 was 33 years old, has been less than 1 cent per square yard per year. This street is 92 feet between curbs and has an excellent crown. It was said to be in good condition in 1912, except for a few spots which showed signs of disintegrating. These defects were supposed to be due to illuminating gas.

In 1883 the first asphalt pavement west of the Missouri, and probably of the Mississippi River, was laid in Omaha, Neb., on Douglas Street, by the Barber Asphalt Paving Co. At that time no asphalt pavement had been laid over five years, and the company had not been able to determine from experience what was the best method of laying the pavement. It has always been considered that the sand in the vicinity of Omaha does not make the best mixture, and the climate is exceedingly bad for an asphalt pavement, varying from 30 to 35 degrees below zero in the winter to 125 or 130 degrees above in the sun in the summer. Despite these unfavorable conditions this pavement was not relaid until 1908.

The Borough of Brooklyn at the present time has one pavement that has been out of guarantee 9 years, and the total cost for repairs has been 3 cents per square yard. Another that has been out of guarantee 10 years, the foundation being partly concrete and partly an old bituminous-concrete pavement, has cost 4.7

cents per yard for the entire 10 years, and for the last year cost but 2 mills per yard.

The foregoing examples are given as illustrations of what asphalt can do in exceptional cases. It might be said that if pavements could be laid of such durability at one time it would be possible by duplicating them to obtain the same results. While this may seem logical as a matter of fact it has never been possible to do it.

The Surface Heater.

It often happens that an asphalt pavement after it has become old and worn still contains a good deal of valuable material, but in such shape that ordinarily it is of no value. It may be full of depressions and bunches, making the surface too uneven for practical use, although containing practically the original amount of material. Several methods have been tried for heating the surface of this material, raking it down, and then adding sufficient wearing surface to bring it to the proper grade and contour. With the early machines the heating was done by means of a flame, which would often burn the asphalt to such an extent as to injure it, also heat the pavement outside of the required bounds. Recently, however, a machine has been patented by which this heating is done by hot air rather than by flame. The machine consists essentially of a traction engine to which is attached an apparatus for heating the air and blowing it out upon the pavement at a temperature that will soften and melt the asphalt. The hot air is applied to the pavement through a pipe to which is attached a hood 5×10 feet square, which can be lowered down as close as is necessary to the pavement. After the asphalt is heated the machine is backed away, when the material on the surface is scraped off and a new wearing surface applied in quantities sufficient to bring it to proper thickness.

This machine has been used to some extent in Washington and also in Brooklyn. The Washington report for 1910 states that the machine is economical when the amount is about 1 inch, and on work done during the previous year the cost had been 70 cents per cubic foot of material used, averaging 64 cents per square yard.

In the Borough of Brooklyn for 1911 this machine was used, the work being done by the city's employees at a cost of about 74 cents per square yard. For 1912 several contracts have been let for resurfacing a large area of pavement, the contractor to be paid by the cubic foot for material used. The contract price was 64 cents per cubic foot of wearing surface and 32 cents for binder. The cost per yard of completed work varies with the depth of material used, but will generally average about 70 cents. This makes a material saving over taking up the old pavement and laying a new one.

One machine will treat from 400 to 450 square yards of pavement in 8 hours.

The condition of the pavement and its foundation will determine whether it is economical to use this method or not.

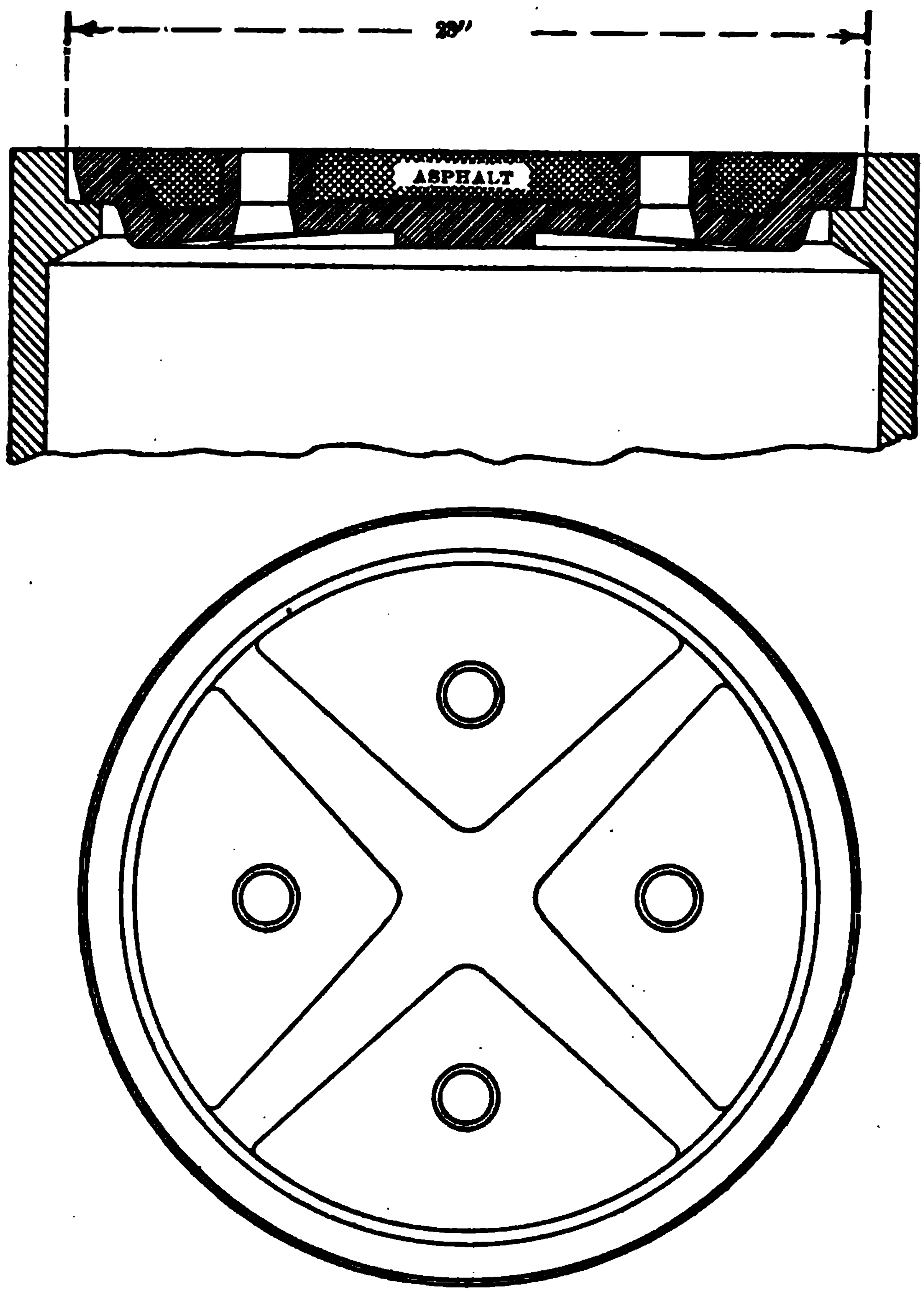
In some of the Denver, Colo., specifications a proposition was made for making a contract for repairs for an additional 10 years after the expiration of the guarantee period, at a cost not to exceed 10 cents per yard per year. In the early specifications of Newark, N. J., the city agreed to pay the contractor 5 cents per yard per year for the 10 years following the 5-year guarantee.

European pavements have cost considerably more than those of the United States. This is attributable principally to the increased traffic. The average cost of maintenance per square yard in Paris for 1893 was 37 cents. In Berlin it was 10 cents per yard per year for a period of fifteen years after the guarantee period had expired, and on railroad streets 15 cents for space between tracks and for a distance of 27½ inches outside. In London in 1882 the average cost of twenty-eight streets was 21 cents per yard. In Glasgow a sinking fund of 10 per cent is provided in the case of asphalt for maintenance and repairs. In Leith, Scotland, one asphalt street cost 5 cents per yard per year for fifteen years following the third year after being laid.

Noiseless Manhole Covers.

On streets paved with asphalt, where sewer manholes occur at frequent intervals, complaints have often been made of the noise caused by the wheels of vehicles running from the asphalt over the

iron manhole cover. To obviate this trouble a cover shown in Fig. 19 has been used successfully in Brooklyn.



UNDER SIDE OF COVER.

FIG. 19.

The covers are taken to the contractor's yard and then filled with the asphalt mixture, when they are distributed on the different streets as may be desired.

Cost of Asphalt.

The Borough of Brooklyn for some years has been purchasing its asphalt for its repair work in the open market by competitive bidding. It contracted for 2000 tons in the spring of 1912 under specifications that called for the asphalt to have not less than 50 per cent of bitumen soluble in carbon bisulphide, 65 per cent of the bitumen itself to be soluble in boiling Pennsylvania petroleum naphtha, 98½ per cent to be soluble in carbon tetrachloride; 20 grams of the refined asphalt, heated 5 hours at a temperature of 325° F., should not lose more than 5 per cent by volatilization, the penetration at the end of that time not to be less than one-half of the original. The refined asphalt to be not softer than .50 of a centimeter at 77° F., and not to require more than 35 per cent of flux to produce that penetration. The ductility of the asphalt cement to be not less than .25 of a centimeter at 77° F. Asphalt made by distilling asphaltic oil to have a penetration of not more than .50 nor less than .35 of a centimeter. The asphalt to be uniform and not vary more than .07½ of a centimeter from the penetration of the sample.

The specifications also state that the price paid shall be according to the bitumen contained in the asphalt, the contractor to state the amount of bitumen contained, and the prices made by the different bidders to be reduced to an asphalt containing 100 per cent of bitumen and the lowest bidder determined in that way. It was also provided that 3 per cent of the price should be deducted for every .02 of a centimeter the asphalt varied above the maximum or below the minimum, or should be rejected in the discretion of the engineer. Ratable deductions to be made also in the amount of bitumen contained in the asphalt when it was 2 per cent less than the sample.

Under these specifications the following bids were received and the contract awarded to the lowest bidder.

Kind of Asphalt.	Price per Ton.	Percentage of Bitumen.	Corrected Price.
Mexican	$15.25	99.5	$15.33
Trinidad	20.80	56.0	37.14
Bermudez	27.25	95.0	28.68
Texas	18.50	99.8	18.54
Another Mexican	19.17	99.5	19.27
California	22.38	99.5	22.49

In Detroit during the 8 years the Municipal Plant has been in operation the price has averaged:

For Bermudez	$27.00 per ton
" Trinidad	22.00 " "
" Acme	25.00 " "
" Obispo	30.00 " "
" Cuban	22.00 " "

Cost of Asphalt Pavements.

In the operations of the Brooklyn Municipal Asphalt Plant all work is done in making repairs either in patches or repaving over trenches. The men work 8 hours and the prices for labor probably exceed that in other cities. The following shows the costs of this plant for 1911 for repaving over trenches:

	Wearing Surface.	Binder.
Supervising and fixed charges	$0.025	$0.024
Supplies, repairs, etc	.067	.057
Material	.178	.097
Plant labor	.046	.043
Street labor	.182	.174
Trucking	.060	.057
Total	$0.558	$0.452

Assuming that it will take 1.76 cubic feet of wearing surface and .8 cubic feet of binder per square yard the cost will be:

1.76 cubic foot wearing surface at $0.558	$0.98208
.80 cubic foot binder at $0.452	.36160
Total per yard	$1.34368

The cost of material for the above was:

Refined asphalt	$21.56 per ton
Residuum oil	.07½ per gal.
Binder stone	1.09 per cubic yard
Sand	.53 per cubic yard

The mixture per batch at the plant was:

Asphaltic cement	98 lbs.
Stone dust	150 "
Sand	810 "
Total	1058 lbs.

The Detroit Municipal Plant reports as follows for the 8 years it has been in operation:

COST PER SQUARE YARD.

REPAVING AND RESURFACING 1½″ BINDER, 2″ TOPPING COMPACTED, PATCHING AVERAGE 3″, MOSTLY TOPPING.

	Square Yards.	Labor and Material.	Overhead Charge, Table *B*.	Total.
Resurfacing	834,170.20	.87003	.06864	$0.93867
Paving and repaving	304,995.26	.87135	.06864	0.93999
City and private patching	220,281.15	.99160	.06864	1.06024
Total yardage	1,359,446.61			

The cost of asphalt in Detroit has already been given. The cost for the other materials are:

Binder stone, per ton, $0.75	$0.75
Limestone dust, per ton (in paper sacks)	3.40
Sand per cubic yard	.67
Fluxing oil, Eastern, per ton	10.00
" " Texas, per ton	17.00
" " California, per ton	23.00

In a paper read before the American Society of Municipal Improvements in 1909, Mr. C. H. Rust, City Engineer, Toronto, gave the cost of laying an asphalt pavement in that city in the same year on Sackville street (1651 square yards, wearing surface 2 inches thick, binder 1 inch thick) as:

Labor		$70.50
157 batches binder at $1.98	$301.44	
Cartage	24.95	
Top, 275 batches at $2.70	742.50	
Cartage	36.15	
Asphaltic cement, 175 lbs. at $1.87	3.24	
Stone dust, 400 lbs., at 30 cts	1.20	
18 hours roller at $1.40	25.20	
Half cord slats at $6.00	3.00	
		$1137.18
Total		$1208.18
Per yard		0.733

Dunn avenue, Toronto, figured per square yard:

Laying binder	$0.014	
Carting binder	.027	
Material binder	.157	
Rolling binder	.016	
		$0.214
Laying surface	.034	
Carting surface	.051	
Material surface	.448	
		0.533
		$0.747

In the same year asphalt repairs cost $0.679 per square yard laid.

Asphalt for Bridges.

Asphalt pavement has been laid on several bridges. Perhaps the most notable case of this kind is the Fourteenth Street viaduct in Denver, Col. One section of this structure is of steel for a length of about 1500 feet, having a grade of 4.25 per cent for a distance of 400 feet. The entire roadway is paved with asphalt on a concrete base.

Expansion-joints are provided at every other post, making them from 40 to 60 feet apart, according to the length of the bents. At these joints three-inch openings were left in the concrete extending across the roadway.

When the asphalt was laid these openings were filled with paving mixture and tamped flush with the top of the concrete, and the wearing surface laid over the whole. While still hot a cut was made

on the line AB, Fig. 20, and then filled with hydraulic cement, in order to prevent the edges from adhering under the action of the roller, and to allow the contraction to occur at one place should there be any appreciable amount.

While this pavement was only laid in September, 1899, in May, 1900, it was in good condition, including the joints, although it

A

Fig. 20.

had been subjected to a temperature of 20° below zero the preceding winter.

American Asphalt in London.

Trinidad asphalt has been used to a slight extent in Europe, but seems to have gained its greatest credit on the Thames Embankment in London. For many years the London authorities have been experimenting with different materials on the embankment, the later ones beginning in 1905. In 1906, among others, an area of 800 square yards of Trinidad asphalt was laid on an asphalt binder; the price, including the excavation of the old pavement and 2 years' maintenance, was 9s. per square yard. Other pavements laid at this time lasted some of them only a few months. In 1908, when the period of maintenance expired for the Trinidad asphalt, the pavement had shown no sign of failure, and the contract was renewed for 3 years longer at the rate of 6d. per square yard per year. At the same time some 8000 yards more of the same pavement were laid in detached areas,

at a cost of 9s. per square yard and maintenance for 5 years, not including the excavation. The other materials that had been laid continuing to wear out, in 1909, 15,750 square yards more were given to the Trinidad Company on the same conditions. In 1911 further agreements were entered into with the Trinidad Lake Asphalt Paving Company for further maintenance for one year of the area laid down in 1906.

The Engineer of the London County Council, in speaking of this pavement in 1912, said:

"The Trinidad Lake asphalt laid on a binder course has undoubtedly proven the best under the traffic conditions of the Victoria Embankment. It is much cheaper then the usual asphalt pavements, consisting of rock asphalt laid on concrete, and its surface appears to wear equally well; and the substitution of the asphalt binder course under the hard asphalt top coating instead of the usual concrete bed, appears to some extent reduce to the noise of traffic."

The pavement is described as a 3-inch binder course, laid over the old macadam after it had been picked up and resurfaced to a true contour, with a wearing surface 1½ inches thick, the composition of the wearing surface being approximately: bitumen, 11.5 per cent; Portland cement, 15 per cent; silica, 73.5 per cent.

In speaking of the traffic on the embankment the engineer says:

"The traffic on the Embankment amounts to an average of 10,152 vehicles (excluding tramcars) daily from 8 A.M. to 8 P.M., and the average width of the roadway is about 64 feet, including channels, of which, however, 17 feet is occupied by the tramway lines. Owing to the frequency of running, and the speed of the tramcars, this width of 17 feet which is paved with granite setts is not much used by ordinary vehicles.

"The effective width of the roadway for ordinary traffic therefore averages 45 feet, and the volume of traffic amounts to 159 vehicles per foot of width over the whole roadway, or 225 vehicles per foot of width if the area occupied by the tramlines be excluded. It is believed that no other road constructed of ordinary macadam ever carried such a volume of traffic per foot of width.

"For purposes of comparison it may be pointed out that the traffic in the Strand opposite the Law Courts (wood paving) amounts to 311 vehicles, and that in Ludgate Hill (also wood paving), in front of St. Paul's Cathedral, to 296 per foot of width."

Asphalt Block Pavement.

Another form of asphalt pavement is that known as asphalt block. Blocks of crushed stone and Trinidad asphalt were first made in San Francisco in 1869. The machinery, however, was very crude, hand-moulds being used, and the compressing was done by men. The results, as might have been expected, were poor, but the success of the blocks was such that their manufacture was continued to a greater or less extent for ten years when, about 1880, the invention of a powerful mechanical press made the manufacture of improved blocks possible and successful. From that time on, improvements have been made upon the methods and machinery.

For quite a number of years the blocks were made of limestone, but in 1893 trap-rock was substituted for the limestone. Blocks made of this latter material give much better satisfaction on account of the greater durability of the trap-rock, and at the present time that material is being used entirely in the manufacture of the blocks. Asphaltic cement is mixed with the trap-rock in proper proportions at a temperature of about 300°. The material is placed in a press at this temperature and each block is subjected to a pressure of 120 tons. After leaving the press the blocks are gradually cooled in a water-bath, and are then ready for use.

In the earlier years of the industry blocks were made $4 \times 5 \times 12$ inches. A depth of 5 inches, however, was considered to be unnecessary, and the present practice makes them of the same dimensions as above, except that the depth is 4 and 3 inches, the blocks weighing 13½ and 18 lbs. respectively. These blocks are carried to the street and laid upon a base of either gravel, broken stone, or concrete, as the case may be.

The blocks are laid in practically the same manner as are bricks, the joints being filled with fine sand. The advocates of this system claim the advantage of uniformity in manufacture; that the materials are always mixed in exactly the same proportions and at

the same temperatures; that the blocks are made under cover and are not subject to any differences on account of changes in the weather; also that, as the blocks are manufactured at one central plant, they can be used in cities of small size without the expense of the location of portable plants. These arguments are good, but, as all the material must be first transported to the plant and then the blocks carried to the place where they are to be used, the cost of this double transportation in some localities prevents them from competing successfully from an economical standpoint with the sheet asphalt. Wherever used, good asphalt blocks have given satisfaction. It is claimed that they can be laid successfully on much steeper grades than sheet asphalt, and that, on account of their being so very solid and compact, they do not require as thick a concrete base as the sheet asphalt. On January 1, 1911, there had been laid in this country 9,544,172 yards of this class of pavement. Quite an amount also has been laid in South America, and some in Europe.

The early asphalt block specifications were indefinite because little was known as to the best methods of construction. Experience, however, has made it possible to specify certain conditions which will it is thought insure a good block. The requirements of the Borough of Brooklyn, New York City, are that the blocks shall be made of trap rock as nearly cubical as possible, and in no case shall the maximum size of any piece be more than three times the minimum. All stone shall pass a ¼-inch screen. Not less than 40 per cent of it shall be retained on a 20-mesh sieve, and not less than 12 per cent shall pass a 100-mesh sieve. If the stone naturally does not contain this fine material it can be added; in any case not less than 6 per cent of added dust shall be used. The blocks shall contain not less than 5¾ nor more than 8 per cent of bitumen. Of the mineral matter not less than 18 per cent shall pass a 100-mesh sieve. The specific gravity of the blocks shall be not less than 2.5.

After being dried for 24 hours at a temperature of 150° F. the blocks shall not absorb more than 1 per cent of water in 7 days. The specific gravity and absorption tests provide for a dense block.

Experiments have been made to determine the wearing qualities of the blocks, or the comparative merits of different blocks, by an abrasion test, in which a machine corresponding somewhat to the rattler for brick tests has been used, except that the panels are made of the blocks themselves, but these experiments have not been continued long enough or to such an extent as to warrant establishing a standard at the present time.

The cost of asphalt-block pavement varies with location of city, depth of blocks, character of foundation, etc.

For 3-inch blocks laid on Portland cement concrete 5 inches thick the price in Brooklyn in 1911 was $2.55 and for 2-inch blocks $2.11 per square yard.

Another form of asphalt blocks is sometimes used in which the broken stone is replaced by granulated cork. Such blocks were laid on Fifth Avenue, New York, between Thirty-fourth and Thirty-sixth streets, in strips ten feet wide, adjacent to the curb. The grade on these two blocks being somewhat steeper than the remainder of the avenue, it was deemed best to provide a better foothold for horses in slippery weather than the ordinary asphalt. The blocks are $2 \times 4\frac{1}{2} \times 9$ inches and were set flatwise. This pavement was laid in the fall of 1897, and in the spring of 1900 was in very good condition. It cost $5.25 per square yard, exclusive of foundation, under a fifteen-year guarantee.

The cork blocks were not satisfactory and in a few years they were replaced with sheet asphalt.

Bitulithic.

About the year 1900 a gentleman who had been previously connected with the asphalt pavement industry conceived the idea of constructing an improved macadam pavement with a bituminous binder. In the development of his idea he gradually evolved a pavement that was a bituminous pavement containing some of the characteristics of asphalt, but differing from it in many particulars, the mineral aggregate being made up mainly of broken stone rather than sand. His idea as developed was that the

broken stone should be stable enough to sustain the load itself, and he felt that if the voids in the broken stone were reduced to a minimum this result could be accomplished. By a long series of experiments and scientific determinations a combination was obtained by which the voids were reduced to practically 20 per cent. By the use of stone thus graded, combined with the bituminous product, a pavement has been developed that isconsidered standard. This pavement is known by the trade name "Bitulithic."

Up to February, 1912, twenty million square yards of this pavement have been laid in ninety-nine cities in thirty-five States.

This pavement, like all others, should have a good and substantial foundation. If the street to be improved has once been paved with macadam, stone blocks, cobble, or brick, this pavement has been successfully laid over the old pavement.

Another form of foundation for this pavement is made of broken stone or slag laid to a depth of from 4 to 6 inches, or possibly more, according to the character of the subsoil and the traffic to which the pavement will be subjected. This foundation is thoroughly rolled with a steam road-roller. Before laying the foundation stone the subgrade must be thoroughly rolled. Upon the surface of the foundation stone is then spread a heavy coating of bituminous cement. Where desired and deemed necessary the ordinary concrete foundation is used. The surface of the concrete should be left rough so as to allow a good bond between the wearing surface and the foundation.

Surface.—Upon the foundation is spread the wearing surface, which is compressed with a heavy road roller to a thickness of 2 inches. The surface mixture is made of the best stone obtainable, varying in size from a maximum of about 1 inch down to an impalpable powder, the various sizes of smaller stone, sand and impalpable powder being provided to fill the spaces between the larger stones. The proportions used of the various sizes of mineral are predetermined by physical tests with a view to obtaining the smallest percentage of air spaces or voids in the mineral mixture, and vary with the character and shape of par-

FIG. 21.—Cross-section of Bitulithic including Bituminous Base.

FIG 22.—Cross-section of Bitulithic.

ticles of the stone used in each particular case. After the proportions have been determined, the mineral material is passed through a rotary dryer, from which it is carried up an elevator and through a rotary screen which separates the mineral material into its several different groups of sizes. The proper proportion by weight of each of these sizes is secured by the use of a scale having seven beams, the exact required amount being weighed out, and run into a double-shaft rotary mixer. There it is combined with a bituminous cement which is also accurately weighed in the proper proportion. The whole is then thoroughly mixed together and dumped, while still hot, into carts, hauled to the street and spread and thoroughly rolled with heavy steam-road rollers.

Grit Surface.—After the surface is thoroughly rolled, a flush coat of bituminous cement is applied to the surface, thoroughly sealing it and increasing its waterproofness. There is then applied a thin layer of finely crushed stone about ½ inch in size, according to the roughness of the surface desired. The pavement is again thoroughly rolled, leaving the street in a finished condition. In some cases a fine mixture of mineral aggregate and bituminous cement called " mineral flushcoat " is used instead of the flushcoat of bitumen and screenings.

Adaptability of the Bitulithic Pavement.—As the stone supports the traffic, it is not necessary to rely upon the bituminous cement to give the necessary rigidity to enable the pavement to sustain traffic. The bituminous cement makes the pavement waterproof and binds the mineral ingredients together so as to prevent action of water and the picking out of these particles by the horses' hoofs. The bituminous cement used is sufficiently soft so that the pavement will not crack in cold weather, and as the stone itself sustains the traffic the softness of the cement is no detriment in summer. Bitulithic pavements do not crack.

This pavement was first laid in Pawtucket, R. I., in 1901. It was laid on a street that had grades ranging from 4.9 to 12 per cent. On account of these grades it had been difficult to keep the street in condition, as it was paved with ordinary macdam

and washed badly during heavy rains. The pavement after having been laid 11 years was in very good condition, and no trouble from washouts had occurred.

Bituminous Concrete Pavements.

Previous to 1910 all repaving in New York City was paid for by the city at large without regard to the character of the original pavement.

In that year an amendment was made to the charter of the City of New York by which a secondary pavement could be laid and the cost assessed against the abutting property, this to be followed when worn out by a permanent pavement, the difference only between the cost of the secondary pavement and the permanent pavement to be assessed on the abutting property. The idea of this was that in outlying sections of New York City there is considerable property which could not stand an assessment for a high-class pavement, but which requires something of a temporary nature. Under this law the Borough of the Bronx has laid considerable pavement, which it has called "asphaltic concrete." The asphaltic cement used complies practically with that required for the ordinary asphalt pavement. The specifications for this pavement are as follows:

"The finished pavement shall contain between 7 per cent and 11 per cent of bitumen soluble in carbon disulphide, depending upon its mesh composition, but in all cases sufficient asphalt cement shall be used to thoroughly coat all the particles of the mineral aggregate.

"The mineral aggregate shall be proportioned as follows:

"Mineral aggregate passing 200-mesh screen, from 5 to 11 per cent.
"Mineral aggregate passing 40-mesh screen, from 18 to 30 per cent.
"Mineral aggregate passing 10-mesh screen, from 25 to 55 per cent.
"Mineral aggregate passing 4-mesh screen, from 8 to 22 per cent.
"Mineral aggregate passing 2-mesh screen, less than 10 per cent.
"Screens to be used in the order named.

"The mineral aggregate shall be composed of gravel or trap rock screenings and sand, which shall be used in porportions as may be determined by the Engineer according to samples of material to be furnished by the Contractor approximating three of gravel or screenings to one of sand, within the requirements of Section 56. It shall be heated in mechanical revolving dryers, at a temperature not exceeding 325° F., after which the asphaltic cement at the proper temperature and in the proper proportion shall be added, and the entire mixture then placed in revolving mixers and thoroughly agitated until all particles of the mineral aggregate are thoroughly and completely coated with hot asphaltic cement. The mixing shall be continued until the combination is a uniform bituminous concrete.

"The surface mixture prepared in the manner above described, shall be brought to the street in wagons at a temperature between 250° and 350° F., and it shall be protected with canvas covers while in transit. The temperature of the surface mixture, within these limits, shall be regulated according to the temperature of the atmosphere and the working of the mixture. On reaching the street, it shall be dumped on a spot outside of the space on which it is to be spread. It shall then be deposited roughly in place by means of hot shovels, after which it shall be uniformly spread by means of hot iron rakes in such a manner that after having received its final compression by rolling, the finished pavement shall conform to the established grade and crown, and shall have a thickness of not less than 2 inches. Before the surface mixture is placed, all contact surfaces of curbs, manholes, etc., shall be well painted with hot asphaltic cement.

"The wearing surface shall thoroughly compressed by a steam roller, weighing not less than 200 pounds to the inch width of tread, and the rolling continued until a satisfactory compression is obtained. Portions of the pavement that are defective in finish, compression or composition, or that do not comply in all respects with the requirements of these specifications, shall be taken up and replaced with suitable material properly laid, at the expense of the Contractor. A space of 12 inches adjoining

the curb shall be coated with hot asphaltic cement, and the same ironed into the pavement with hot smoothing irons."

In the Borough of Queens, New York City, there are many miles of old roads that were paved with water-bound macadam some fifteen or more years ago. These roads are not to permanent line or permanent grades, but are used to a great extent by automobiles and truck gardeners. In 1911 bids were received for resurfacing some miles of these roads with a bituminous material. The specifications require that the old macadam be cleaned, scarified or picked up, loosened and reshaped to form the foundation of the new roadway; also, that the roadway as reshaped shall be thoroughly rolled by a 10-ton macadam roller. Bids were received for three forms of bituminous pavement, method A (which is practically the same as that described for the Borough of the Bronx), method B and method C.

Method B—Warrenite.—" Upon the foundation prepared as hereinbefore described shall be laid the Warrenite surface-paving mixture, which shall be composed of carefully selected sound hard crushed stone (with or without the addition of sand), or gravel, mixed with the asphalt cement, which must comply with the specifications for asphaltic cement hereinbefore set forth.

" The mineral aggregate in the Warrenite mixture shall be combined within the following proportions:

" Asphaltic cement from 5 to 10 per cent.

" Forty per cent to sixty per cent large enough to remain on a screen having circular openings ½ inch in diameter;

" Ten per cent to twenty per cent fine enough to pass ½-inch screen as above and remain on a screen having circular openings ¼ inch in diameter;

" Ten per cent to five per cent fine enough to pass ¼-inch screen as above and coarse enough to remain on a screen having 100 openings per square inch;

" Ten per cent to five per cent fine enough to pass a screen having 100 openings per square inch as above and remain on a screen having 900 openings per square inch.

" Ten per cent to five per cent fine enough to pass a screen having 6400 openings per square inch at least one-fourth of which

shall be fine enough to pass a screen having 40,000 meshes per square inch;

"The balance shall be of such size as will pass screen having 900 openings per square inch, and remain on a screen having 6400 meshes per square inch.

"It shall be heated in a mechanical revolving drier at a temperature of not less than 225 degrees and not more than 325 degrees, and pass from the mechanical revolving drier into an approved form of mixer. In this mixer shall be added the asphaltic cement within the proportions hereinbefore described. This mixing shall be continued until the combination is a uniform bituminous concrete.

"The mixture shall be delivered in carts suitable for the purpose at a temperature of not less than 180 deg. F., and dumped on platforms, from which platforms it shall be carefully shovelled upon the prepared foundation and evenly spread with hot iron rakes to such a depth that it will have a thickness of two (2) inches after having been thoroughly rolled with a steam roller weighing not less than ten (10) tons.

"After rolling the wearing surface there shall be spread over it while it is still warm, a thin coating of asphaltic cement by means of a suitable flushcoat spreading machine, so designed as to spread quickly over the surface a uniform thickness of flushcoat composition. This spreading machine shall be provided with a flexible spreading band and an adjustable device for regulating to any desired amount the quantity and uniformity of flushcoat composition to be spread.

"Upon this flushcoating fine gravel, sand or stone screenings shall be spread in sufficient quantity to cover the flushcoating."

Method C—Amiesite Pavement.—"The stone or gravel shall be coated with asphaltic cement. The mixing and coating must be done by a machine suitably designed for the proper coating of the aggregate. The mixture shall be manufactured in two grades, grade one for the bottom course, and grade two for the top course.

"The asphalt cement shall contain not less than ninety-five

(95) per cent of bitumen chemically treated and mixed in such a manner that it will remain in a friable and granulated condition when cold and stored in bulk. The stone or gravel and asphalt cement shall be so mixed that each particle of stone or gravel shall be thoroughly coated with the cement. This mineral aggregate shall remain friable so that it can be laid successfully while cold any without and additional heating.

"The mixture for the lower course shall be a mineral aggregate as above specified, of mixed stone running from one-half (½) inch to one and one-half (1½) inch in size, or gravel one (1) inch to one-quarter (¼) inch, and in such proportions as will be satisfactory to the Engineer, the same being coated as above specified. The mixture in the lower course shall be spread to insure an even distribution of the material, and rolled. If any depressions appear from any cause whatsoever, they must be filled with additional material as called for in this course and further rolled until the surface is uniform and to the proper subgrade and crown for a depth of one and three-quarters (1¾) inches after thorough rolling if laid cold, or to a depth of one and one-half (1½) inches if laid at a temperature not less than 180 deg. F.

"The mixture for the top wearing course shall consist of a mineral aggregate ranging in size from one-quarter (¼) inch or less, to one-half (½) inch, in such proportions as will be satisfactory to the Engineer, the same to be coated with asphaltic cement as specified above. This mineral aggregate shall be evenly spread, and shall be rolled until it is compacted and true to the grade and crown and cease to creep in front of the roller and shall have a depth of three-quarter (¾) inch after thorough rolling if laid cold or to a depth of one-half (½) inch if laid at a temperature not less than 180 deg. F.

"Each layer of the work shall be kept as free as possible from dirt so that it will unite with the succeeding layer.

"The stone or gravel for Grade No. 1 and Grade No. 2 mixture must be free, or practically so, from all stone dust.

"After rolling, as above specified, and while the pavement is thoroughly free from moisture, a filler of clean, sharp sand or screened pea gravel, free from loam and clay, shall be spread

in such quantity and to such thickness as will be required to fill in spaces between the units of the surface and then the surface shall again be rolled, after the roadway may immediately be thrown open to traffic. All surplus sand shall be swept off the road.

"After mixing the material shall be hauled to the site of the work in carts suitable for the purpose, dumped on a platform and shovelled and evenly spread over the roadway."

For the last four or five years a bituminous macadam pavement has been laid in Laconia, N. H., with coal tar as the cementing material. The City Engineer describes the construction of this pavement as follows:

"The gravel surface of the street to be paved was removed to a depth of 5 inches below the finished grade at the centre of the roadway and a depth of 4 inches at the gutters. The subgrade was then thoroughly rolled with a 10-ton steam roller, all depressions being carefully filled with selected material. On the subgrade was laid a 5-inch course of broken stone 2½ inches in diameter. After rolling this course a 1-inch stone was spread in even quantity to fill the larger voids in the 5-inch course, and the whole rolled to an even surface. 'Tarvia,' heated in tank cars, was then applied at the rate of 1¼ gallons per square yard by means of a sprayer drawn by the steam roller, care being taken to secure an even distribution and to have the road surface free from dust and dirt. A layer of nut or 1-inch stone was then spread to a depth of 1½ inches and rolled. The voids in this were filled with pea stone from ¼ to ½ inch in diameter, and the surface again rolled. A second application of 'Tarvia X' was then made at rate of from 1 to 1¼ gallons per square yard; and a ½-inch coat of clean, sharp sand spread over the surface and broomed in. The pavement was then given a final rolling and thrown open to traffic."

The average cost of this pavement has been 68.9 cents per square yard. The engineer states that the pavement is giving excellent satisfaction, and the cost of maintenance is decreasing from 4 or 5 cents per square yard for the first year after the

pavement is laid to 2 cents the fourth year. The author has seen some of these tar pavements in New Hampshire and has been surprised at their durability, especially in that climate.

These examples of cheaper pavements have been given so that they can be used if occasion demands. The "Warrenite" and "Amiesite" described are patented.

CHAPTER IX.

BRICK PAVEMENTS.

Brick pavements have been used in Holland since the thirteenth century. In the seventeenth century the roads from the Hague to the Scheveningen were paved with brick. These brick were $7\frac{3}{8}$ inches long, 2 inches wide, and 4 inches deep. Holland, having no natural material of its own suitable for pavements, was fortunate in being able to make bricks out of the silt and deposits of the river, which have been very successful in pavements. Some stone has been used in the larger cities, most of it having been brought from Sweden. Amsterdam and Rotterdam at the present time use brick quite extensively. The life of the brick pavement there is said to be on an average of from ten to twenty years. In Amsterdam it is generally used on one side for ten years, when the bricks are turned, after which they will last about four years, making a total life of fourteen years. The foundation is usually a bed of sand from 8 to 12 inches deep.

It is said that Japan has had brick pavements for more than one hundred years, and one authority gives the dimensions of the brick as 7 inches long, 4 inches deep, and $1\frac{1}{2}$ inches thick. Inquiry made of the authorities in Yokohama elicited the following reply:

"I have to say that the brick pavements in use in Osaka since very ancient times are composed of broken roofing-tiles set on end, usually obtained from *débris* of houses after conflagration. Heavy traffic quickly destroys these pavements."

England has never used brick to any great extent in pavements; but in Staffordshire so-called blue brick, described in detail in a previous chapter, are said to have been in use for about fifty years.

In the United States the first brick pavement was laid in

Charleston, W. Va., in 1870. This was a small portion of the principal street in the city, laid by a private citizen at his own expense, without any encouragement from the city and despite the ridicule of the spectators. The city paid no portion of the expense. The pavement was so good, however, that in 1873 the experiment was continued on a larger scale, the city paying the cost. This latter pavement, although laid twenty-seven years ago, is said to be still good and to have received very little repairs. This brick was a hard-burned building-brick, and samples taken up after having been down twenty years showed a wear of $\frac{1}{4}$ to $\frac{1}{2}$ inch. Its specific gravity was 2.48.

In Bloomington, Ill., in 1875 half a block of brick pavement was laid. The brick were of local manufacture. So successful was this experiment that in 1877 the city made a contract for paving half a block of Centre Street. This street was relaid in 1894, and when taken up the brick were found to be worn about three-quarters of an inch. This pavement consisted of two courses of brick, the bottom course being laid flat and the top course on edge upon it.

Wheeling, W. Va., adopted brick for paving purposes in 1883. These brick were laid on tarred boards on a sand base, with a cushion of about 1 inch of sand between the boards and the brick. Brick in Wheeling have entirely superseded cobblestone, which was the only paving material previous to 1883.

Steubenville, Ohio, laid its first brick pavement in 1884. A letter from the official in charge of streets in 1899 says: "The pavement is still in good condition, has required no repairs, and from present indications will last ten years longer without repairs. These brick were laid on a foundation of 2 inches of sand and 6 inches of gravel, the joints being filled with sand."

In speaking of this pavement in April, 1912, the then City Engineer said:

"The street was repaved under my supervision in 1909, having been down for a period of twenty-five years. The brick at the time of repaving were not entirely worn out. Had they been better supported by a suitable foundation, or had the street been undisturbed by excavation they would probably have lasted five years longer; but within the period for which they

served the street was piped for natural gas, high- and low-pressure water, and sewer, and a single-track street-car line was laid on the centre of the street. The brick with which the street was originally paved were wirecut, 2¼ by 8¼ inches, and when removed at the time of repaving were worn from 4 to 2¼ inches. Without examination or from a distance the end section of the brick appeared square, with of course the rounding of the corners due to wear."

Galesburg, Ill., where, at the present time, so many first-class paving-brick are being manufactured, also first began their use in 1884.

Brick pavement were first used in Zanesville, O., in 1885. The City Engineer in 1899 says: "By reason of relaying the street-railway tracks, this pavement was torn up and relaid three years ago. New bricks were used, as many were broken, and the wedge-shaped bricks used in 1885 were no longer obtainable or desirable. A small part of this portion of the street is still in position and serviceable, showing good wearing qualities."

Peoria, Ill., first constructed brick pavement in 1885. This consisted of two courses of brick, laid on a gravel foundation, with a layer of sand between the two courses. The material was simply hard, specially selected local building-brick. In 1899 the City Engineer said: "The street at present is in very bad condition, and should have been repaved before now. No money has been spent for repairs except for openings for service connections."

Of the larger cities of the country, Philadelphia was the first to adopt brick, laying its first pavements of that material in 1887. So popular, however, did it become there that its use continually increased, until at the present time it has a greater mileage of brick pavement than any other city in the country, and in fact in the world.

New York City, south of the Harlem River, has but one block of brick pavement. This was laid in 1891 on a cement-concrete base, the joints being filled with paving-cement. The work was done (as is usual under such circumstances) as an experiment. The brick with which it was laid were called pyrogranite and were made in New Jersey under a special patent. It was claimed by the patentee that by treating any clay with this process a good paving-

brick could be made. These brick were 8½ inches long, 5½ inches deep, and 2¾ inches thick. Although having been in use nearly nine years, subjected to the heavy traffic of a street-car street, with an elevated structure also in the centre, the pavement in 1900 was in good condition and had received almost no repairs. This pavement was taken up and relaid with granite in 1909 when the entire street was repaved. This being a patented article, and having been so successful, it will be interesting to compare an analysis of this brick with that of the Metropolitan block of Canton, O., which is conceded to be one of the very best paving-bricks.

TABLE No. 61.

	Silica.	Alumina.	Sesquioxide of Iron.	Lime.	Magnesia.	Absorption End-section in 24 Hours.
Pyro-granite.......	73.03	22.46	2.94	0.25	trace	0.47
Metropolitan block	63.74	22.86	8.81	0.65	1.82	1.82

The success of these early brick pavements is somewhat surprising. It is especially so when the quality of the brick used at that time is considered, as well as the method of laying. The brick-manufacturers then had very little idea of the possibilities of a vitrified brick. With too many people a brick simply meant a brick. Then also, with the best intentions, no one was able to select the best material. The best of the brick used at that time would not be considered as a paving material, even, at present. It is not strange, either, that brick were not taken up more rapidly as a paving material. Engineers as a class are proverbially conservative. They never do anything without a precedent unless obliged to. It was hard for them to believe that any artificial product could equal even the productions of nature, but some people did have faith in burned clay, and by their persistent efforts have succeeded in establishing brick in the front ranks of paving materials. In fact, a great many actually believe that it is the best material for street pavements under almost all conditions, and the most radical advocates offer to guarantee a brick pavement to with-

stand the traffic equally as well as granite. That it is bound to be the principal paving material in the Central West, where natural stone can only be obtained at a great expense, and where clays and shales are especially adapted for brick-making, is sure.

To make a good pavement bricks should be hard, tough, strong, homogeneous, impervious to water, and dense.

Hardness.

A paving-brick must be hard in order to withstand the action of the traffic and impact of the horses' shoes. It is the one thing which is naturally looked for by the inspectors on the street, and it is sometimes extremely difficult to draw the line between a hard and a soft brick, between one that should and one that should not be used. The color can sometimes be taken as a guide, and in fact almost always if one is acquainted with the particular make of brick; but it will be impossible to pass judgment upon one make of brick by any standard that has been arrived at from an examination of brick made from entirely different clay. In fact, when a new brick is presented for use, a careful study must be made of its characteristics, so that one may be able to detect the difference by its general appearance. After having determined this, the color is a pretty sure indication of the hardness of the brick. Engineers, as a rule, have not made any attempt to measure the hardness of the brick, and very few specifications say anything definitely upon this subject. Brick, however, can be easily tested for hardness by the use of Mohs' scale.

The scale of hardness as introduced by Mohs consists of the following minerals:

1. Talc: Common, laminated light green variety.
2. Gypsum: Crystalline variety.
3. Calcite: Transparent variety.
4. Fluorite: Crystalline variety.
5. Apatite: Transparent variety.
6. Orthoclase: White cleavable variety.
7. Quartz: Transparent.
8. Topaz: Transparent.
9. Corundum: Cleavable varieties.
10. Diamond.

The hardness of a substance may be found by attempting to scratch it with any of the above minerals. For instance, if a brick will scratch apatite but not orthoclase, its hardness must be between 5 and 6. If it scratches quartz and is also scratched by it in about the same degree, it is of about the same hardness and is consequently 7. To determine the percentage between the above will require considerable practice, as it depends upon the readiness with which one mineral scratches the other.

A rough test for hardness of a paving-brick can be made by attempting to scratch glass. If it slightly scratches it, the hardness can be taken as about 5, and if it scratches it readily, its hardness will be practically 6.

Toughness.

A very hard brick is apt to be brittle, and unless it is tough it will crumble under traffic and be of little use in a pavement. This probably is the most important quality that the brick possesses, as almost any paving-brick is sufficiently hard to withstand the weight of the traffic, but may not be able to endure the blows of the wheels or of the horses' feet.

When an engineer is unable to make a thorough test of any brick submitted for examination, if the test for toughness can be applied and it is satisfactory, he would be comparatively safe in adopting it for use.

Strength.

A brick should be strong, because, on however good a foundation it may be laid, or however well bedded, it is liable to be loaded at times unequally, and if not possessed of sufficient strength is likely to fracture. As vitrified brick are made to-day, however, there is very little danger on these points, and it is very seldom that the brick that will pass the test for hardness or toughness will be rejected on account of its lack of strength.

Homogeneity.

Unless the particles of the brick are perfectly fused and have become one complete new mass, it cannot have obtained its full strength. If it be subjected to any sudden strain, it is liable to

fracture between the particles of which it is made, when, if thoroughly burned and vitrified, the fracture should be regular without any regard to its previous make-up. It should be free from all marks of the machine with which it is mixed, as they both weaken the brick physically and allow spaces for moisture to collect.

Uniformity.

All products of the same kiln should be uniformly burned. While this is sometimes difficult to be obtained, if proper care is exercised in the burning, and the brick are selected at the kiln before shipment, satisfactory results can be secured in almost every instance. A better pavement will result from a lot of brick that are uniformly burned, even if not up fully to the required standard, than from a lot which is perhaps one half perfect and the other half somewhat inferior, for when subjected to traffic the harder brick will maintain their size, while the softer brick will wear and the entire surface soon become rough and uneven and very disagreeable for travel.

Imperviousness to Moisture.

The porosity of a paving-brick is one that can be easily tested and has received considerable attention by engineers. It has been generally considered that 2 per cent is the maximum amount of absorption that a good paving-brick should be allowed. Very few good shale bricks will exceed this, but bricks manufactured from fire-clays, which from their nature are incapable of vitrification, will in almost every case absorb more than this amount. It has generally been considered that the danger of absorption in a paving-brick was similar to that in building-bricks, that is, its liability to disintegrate under the action of frost, but it must be remembered that paving-brick and building-brick are two different substances. In order to reach the point of vitrification brick have been subjected to so severe a heat that they have acquired a strength which is fully able to withstand all actions of the frost, and tests made have borne out this view of the question. Tests for porosity, however, are valuable, as they indicate, in a way not

otherwise possible, the amount of vitrification that has taken place, especially on the exterior. If the brick be thoroughly vitrified it cannot be porous and cannot absorb any appreciable amount of water.

Density.

Density is measured by specific gravity, and specific gravity is measured by the amount of material contained in any substance. If, then, one brick be of greater specific gravity than another, it must contain more wearing material and, other things being equal, will endure longer under traffic. The specific gravity can of course be easily obtained in a laboratory by the usual process.

While it is comparatively easy to specify the qualities that a paving-brick should have, it is not always so simple to decide in what way its different properties should be ascertained when any particular brick are presented for examination. When specifications are made for paving-brick, it is necessary to set some standard with which to compare all samples that are submitted, and also to have a positive and, if possible, simple, method of determining to what extent the samples agree with this standard. Otherwise there will be endless arguments with agents of the different materials, each one claiming every merit for his product and being very prolific in reasons why it should be adopted. The qualities which have generally been considered to be of most importance and for which standards of tests have been adopted are toughness, crushing and tensile strength, and imperviousness to moisture.

In searching for some method of ascertaining the amount of wear that a brick would sustain under traffic on the street, engineers have made many experiments. An experiment which was made several years ago in St. Louis, detailed in the chapter on Pavements, would be satisfactory and conclusive as far as abrasion of the wheels is concerned, but it does away entirely with the action of the horses' feet.

Absorption Test.

An investigation in regard to this test was also made some years ago by Mr. F. F. Harrington. He experimented in a great many different ways, and his conclusions were the result of very careful study, as is shown in detail in his report.

In order to bring the samples to the proper standard of dryness, they were kept in an oven that was constantly maintained at a temperature of from 220° to 240° Fahr.

Table No. 62 shows the results of his investigations in that respect, and the following are his conclusions:

"This chart shows that it requires four days to dry the samples of brick completely and thoroughly, even when the temperature is maintained constantly above the boiling-point of water. This shows how complex and tortuous the pore-channels through the mass of the brick must be, since the water exhausted in them must be superheated and under pressure for the entire time of the test; but while 96 hours is necessary to complete the drying, still the amount of moisture lost in the last half of this treatment is the very small amount of only 5.9 per cent of the total quantity evaporated. For practical work the gain in time of 48 hours on a test is worth more than the reduction to absolute dryness."

Table No. 63 shows the percentages of water absorbed at different intervals of complete immersion.

On another test made with samples from which both ends had been broken, leaving practically half of the brick, the result showed a considerable gain over that for which the whole brick was used. Experiments were also made with small chips from the interior of the bricks which showed the same line of facts as the previous experiment. He concludes that it is doubtful if it would be possible to get complete saturation even if the bricks were first put into the vacuum-chamber and the gas from their pores exhausted. The average increase of absorption of the half-bricks over the whole ones was found to be 16½ per cent in 24 weeks, and the average increase of small pieces over half-bricks and whole bricks in eight weeks was respectively 47.3 and 66.1 per cent. Mr. Harrington favors the use of the brick which have first been used in the rattler test, because the action of the water by absorption takes place quicker with such brick, and also for the reason that they are in practically the same condition as the brick that are exposed in a pavement. His reports having been presented to the commission and discussed, the following points were agreed upon by all:

"1. That all the evidence showed that all data obtained in any

TABLE No. 62.

Brand of Brick.	Percentages of Water Evaporated.					
	2 Hours Drying.	6 Hours Drying.	24 Hours Drying.	48 Hours Drying.	90 Hours Drying.	168 Hours Drying.
Alton Paving-brick Co., Alton, Ill	.070	.085	.120	.185	.135	.135
St. Louis Pressed-brick Co., St. Louis, Mo.	.065	.205	.282	.260	.260	.260
Standard Paving-brick Co., St Louis, Mo.	.210	.320	.395	.525	.535	.535
Purington Paving-brick Co., Galesburg, Ill.	.065	.095	.130	.130	.145	.145
Barr Clay Co., Streator, Ill.	.075	.115	.168	.190	.220	.220
Townsend Paving-brick Co., Zanesville, O.	.030	.062	.095	.110	.130	.130
Moberly Brick Co., Moberly, Mo	.040	.195	.312	.330	.355	.355
Galesburg Paving-brick Co., Galesburg, Ill.	.035	.090	.120	.155	.155	.155
Galesburg Brick and Terra-cotta Co., Galesburg, Ill.	.055	.055	.112	.112	.130	.130
	.045	.060	.087	.120	.120	.120
Average	.065	.127	.178	.210	.220	.220

TABLE No. 63. *

Brand.	Percentages of Water Absorbed.								
	1 Day.	2 Days.	7 Days.	2 Weeks.	4 Weeks.	6 Weeks.	8 Weeks.	12 Weeks.	24 Weeks.
Alton Paving-brick Co.	0.37	0.55	0.65	0.80	1.05	1.29	1.51	1.62	1.73
St. Louis Pressed-brick Co	0.36	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.45
Standard Paving-brick Co	0 44	0.55	0.60	0.70	0 76	0.87	0.96	1 02	1.12
Purington Paving-brick Co.	0.87	1.48	1.76	1.95	2.05	2.20	2.28	2.31	2.48
Barr Clay Co.	0.25	0.80	1.60	2.10	2 30	2.60	2.70	2.74	2.87
Townsend Paving-brick Co.	0.28	0.37	0.48	0.62	0.88	0.87	1.00	1.05	1.20
Moberly Brick Co	1.60	2.65	3.10	3.90	4.10	4.26	4.35	4.55	4.64
Wabash Clay Co., Veedersburg, Ind.	4.60	5.30	5.63	5.87	6.10	6.20	6.35	6.40	6.58
Mack Pav.-brick Co., Pittsburg, Pa.	3.12	3.63	3.87	4.02	4.18	4.20	4.29	4.32	4.35
Imperial Pav.-brick Co., Canton, O.	0.25	0.35	0.37	0.58	0.70	0.85	1.04	1.16	1.28
Des Moines Paving-brick Co., Des Moines, Ia	0.60	0.75	0.76	1.03	1.25	1.45	1.62	1.73	1.87

* Passing 100-mesh.

short test of less than one week is far from representing the actual porosity of the brick.

"2. That the results of short tests are misleading, because the rates of absorption of different samples are widely different.

"3. That in the experience of members of the commission no connection whatever can be traced between a low absorption test and materials of wearing quality in paving-brick.

"4. That paving-bricks which are soft enough to become liable

to destruction by frost showed this structural weakness in the rattler test also."

Consequently the commission decided officially to discontinue the absorption test as a means of determining the value of paving-bricks; but for the benefit of those who might still adhere to its use, the following specifications for conducting the test were adopted:

"1. *Number of Brick.*—The number of brick constituting sample of the official test shall be five.

"2. *Condition of the Brick.*—The brick selected for conducting this test shall be such as have been previously exposed to the rattler test. If such are not available, then each whole brick must be broken in halves before the test begins.

"3. *Drying.*—The brick shall be dried for 48 hours continuously at a temperature of 230° to 250° Fahr. before the absorption test begins.

"4. *Soaking.*—The brick shall be weighed before wet, and shall then be completely immersed for 48 hours.

"5. *Wiping.*—After soaking, and before reweighing, the bricks must be wiped until free from surplus water and practically dry on the surface.

"6. *Weighing.*—The samples must then be reweighed at once. The scales must be sensitive to 1 gram.

"7. *Calculation of Result.*—The increase in weight due to absorption shall be calculated in per cents of the dry weight of the original bricks."

The commission then adopted the following resolution and attached it to the above as a part of their report:

"Resolved, that, in the opinion of this commission, any paving-brick which will satisfy reasonable mechanical tests will not absorb sufficient water to prove injurious in service. We therefore recommend that the absorption test be abandoned from all official tests as unnecessary, if not absolutely misleading."

Size of Bricks.

Paving-bricks have been made of very different shapes and sizes by different manufacturers. Other things being equal, the same principles laid down for establishing dimension of granite

blocks would apply to sizes of paving-bricks; but it must be remembered that while the material of which the granite blocks are made is natural, that composing the bricks is artificial. Consequently new conditions arise, and in determining dimensions consideration must be given to the method of manufacture. If the brick is made too long, it is liable to warp either in the preliminary drying or while it is being burned in the kiln. If it is too thick, so that the clay in the interior is vitrified with difficulty, it is probable that when sufficient heat has been applied to insure proper vitrification to the central part of the brick, the outside will have been damaged and the brick not of uniform texture throughout, so that in determining the thickness the same rule will not apply to all clays, as some clays will vitrify more readily than others. But a thickness must be adopted for any particular clay which will admit of complete vitrification at a temperature which will not injure any portion of the brick.

Then, too, apart from the physical conditions governing the size, the economic reasons must be considered. If brick are made of an unnatural size as compared to building-brick, underburned brick, which are always found in greater or less extent in every kiln of paving-brick, will be almost a total loss, as they can be used to very little advantage for any other purpose; while if of about the standard size of building-brick, the soft brick can always be disposed of to builders without loss.

Bricks have been made, however, and used in pavements, having dimensions as large as $4 \times 5 \times 12$ inches, but for the above and other reasons their use has been discontinued, and at the present time smaller sizes are adopted. Many manufacturers make two sizes, the smaller being practically $2\frac{1}{2} \times 4 \times 8\frac{1}{2}$ inches, and the larger $3 \times 4 \times 9$ inches. These latter are generally termed blocks in distinction from the smaller size. The different standardization committees agree upon the above size for brick, but make the standard size of block $3\frac{1}{2} \times 4 \times 8\frac{1}{2}$ inches.

The National Paving Brick Manufacturers' Association specifications say:

"In size they shall not be less than $2\frac{1}{2} \times 4 \times 8$, no more than $3\frac{3}{4} \times 4 \times 9\frac{1}{2}$ inches."

Form of the Brick.

Whether the bricks should be made rectangular in shape or whether the corners should be rounded off is a mooted question. The argument used by the advocates of the round corner is that if the brick are laid with square edges, the impact of the horses' shoes soon wears them off practically to the round corners, leaving them in a rougher and much worse condition than if they had been originally made round. There is considerable merit in this argument, and if the joints are to be filled with sand or some unstable filler, it is probably the best shape; but if the joint-filler is rigid, like Portland cement or some similar filler, so that the joints can be filled solidly to the top and so maintained, it would seem that the square-edged brick would give better results. With the rounded corner and the joints filled only to the top of the brick a thin edge of the filler must be made at each side of the joint, which is maintained with difficulty under traffic.

Different devices have been adopted for keeping the bricks at a certain distance from each other in a pavement, so that the space may be left sufficiently wide to admit of enough filling material to make a good and substantial joint. Some blocks have a projection on one side to maintain the distance, and a groove on the other side to receive the joint-filling material. It is a well-known fact that, whatever the material composing blocks for pavements, the smaller the amount of joint-space the better. It would seem, therefore, that it was hardly necessary to provide any special arrangement for keeping the brick apart. It has been the author's experience that where the brick were apparently laid tight in the work, when they came to be rammed or rolled sufficient space would be found to receive the proper amount of joint-filler.

Foundation.

The foundation of a brick pavement, like that of all others, is very important. As has been shown before, blocks of any kind wearing from abrasion wear much more rapidly if they are

not exactly level. Thus if the blocks are set and maintained with a smooth even surface, so that the wear is directly on the top rather than on the edges or corners, the abrasion is reduced to a minimum and the life of the pavement correspondingly increased. This is particularly important in a brick pavement, because the blocks are necessarily small and the number of joints and corners correspondingly increased, so that to get the best results the foundation should be such as will allow the brick to be placed in position and so maintained under traffic. Unfortunately for the good name of brick pavements this principle, if understood, has not always been carried out in practice.

Brick pavements have been laid upon foundations of sand alone, a combination of boards and sand, a combination of sand and bricks laid flat, and on a foundation of broken stone and cement concrete.

For reasons specified above, it can readily be understood that a foundation of sand alone cannot be expected to give good results. The weight of a vehicle coming upon any particular brick is transferred to the foundation beneath, and if the foundation be sand, and the underlying earth unstable, any amount of heavy traffic is bound to make such pavement soon appear rough and uneven. The wear then quickly becomes abnormal, and the pavement wears out and is replaced long before it should have been. The early pavements in some places were laid on a foundation of 3 inches of sand, upon which were placed oak boards 1¼ inches thick which had been previously soaked in coal-tar, and this covered with a cushion-coat of 1 inch or 1½ inches of sand. This foundation gave very good results for light traffic, but could not be expected to sustain the heavy travel of business streets.

Another method adopted was laying the bricks flatwise on a bed of sand, rolling and ramming them thoroughly. They were then covered with a cushion-coat of sand, and the surface brick set on edge. This construction has been used to considerable extent in the Central West and with good results. It commends itself to cities located at any distance from stone-quarries, for two reasons: the stone necessary for this foundation, whether used with or without cement, is expensive, and because it gives an opportunity for the economical use of the underburned brick,

which are not suitable for the wearing surface, but have been burned sufficiently to give satisfaction in the lower course. It can be seen that in a locality where brick are readily available and the cost of freight is correspondingly low, and where broken stone is expensive, this would be an economical foundation; but if the brick are to be carried to such a distance that freight is an important item, it might prove to be expensive. The proper plan must be determined upon in each case.

Broken Stone.

In many parts of Illinois where paving-brick have been used to a considerable extent, limestone can be obtained easily and cheaply. Consequently foundations of broken stone, thoroughly rolled and compacted, have been used in many cities with excellent results. With this material, however, care must be taken to roll and compact the stone thoroughly to a hard, firm surface, so that when the cushion-coat of sand is applied and the pavement laid, the traffic will not cause the sand to mix with the stone in the foundation, thus causing a settlement in the pavement and allowing it to become rough and uneven. Several brick pavements have failed from this cause. If, however, the stone be rolled as for a macadam road and thoroughly compacted and made solid, it cannot fail to give good satisfaction if undisturbed.

Cement Concrete.

The best foundation, although its expense in every case may not be justifiable, is cement concrete, such as has been heretofore described. It should be made in the same manner as for asphalt or stone, but care should be taken to have the surface as smooth as possible, so that there will be no danger of any brick resting upon a projecting piece of stone and so getting an unequal bearing, and perhaps breaking under a heavy load. The object of the sand cushion is simply to give the brick a firm bearing, and the smoother the surface of the concrete the smaller the quantity of sand necessary, and the smaller the quantity of sand the less liable is any individual brick to settle out of place.

Fig. 23 represents a cross-section of a brick pavement on a concrete base.

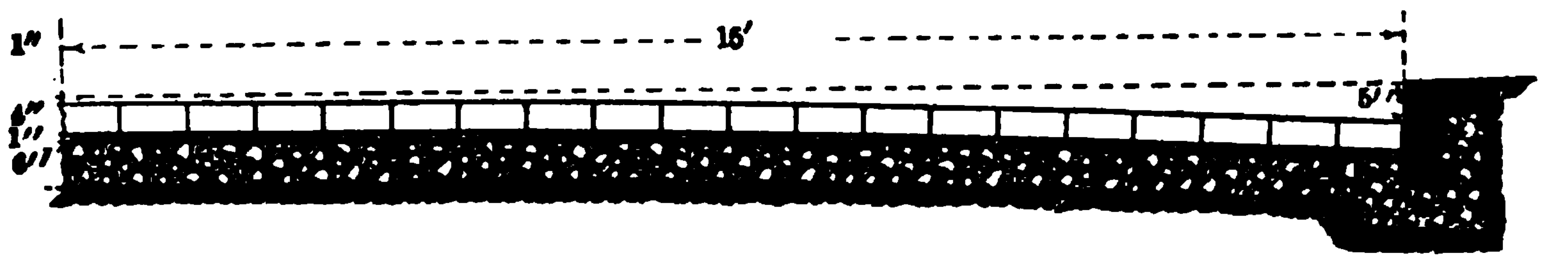


FIG. 23.

Joint-filling.

The material for filling the joints of the brick pavement is practically the same as that used for stone, with the exception of gravel combined with tar. All have been used in different sections of the country, but it is not yet a settled fact which is the best. The City Engineer of Minneapolis in his report for 1898 states that when, during the year, the city asked for bids from manufacturers for furnishing paving-brick, with a guarantee of fifteen years, allowing the bidders to designate the filler which they preferred should be used, one bidder specified sand, and distinctly stated that unless it were used he would not guarantee his brick. It is generally considered, however, that when brick are laid on a solid foundation, a rigid, or at least water-tight, joint-filler should be used. Of these, the two principal ones are Portland-cement grout and the bituminous. Engineers, however, do not agree as to which one of these gives the best results. The former is rigid, and when the joints are once broken they can never be made tight and are little better than a sand joint, while a pitch joint once broken will become solid again at a warmer temperature.

At a meeting of the American Society of Municipal Improvements, held in Toronto in 1899, it was stated by one engineer, in a discussion upon this subject, that he had examined nearly all of the brick pavements laid in this country with a Portland-cement joint, and had come to the conclusion that they were failures. Further on in the discussion another engineer of equal experience stated that it was his belief that a brick pavement well laid with a Portland-cement joint would last five years longer than a similar pavement laid with sand joints. This testimony was corroborated by that of another engineer of considerable experience. The prin-

cipal objection that is made to the use of the cement-grout joint is on account of the rumbling noise that is heard when driving over such a pavement. This does not always happen, but has occurred in a great many instances and is certainly very objectionable. The rumbling must be caused by cavities that exist between the brick and the concrete. Just what causes these cavities is not so well known.

In discussing this subject in a convention of the National Brick Manufacturers' Association, held in Pittsburg in 1898, it was thought by many of the manufacturers that these cavities were caused by a slight shrinkage of the concrete, and their remedy was not to have the brick laid until the cement had become thoroughly set and dry. Other people, and perhaps those who have studied the question more, think it is caused by expansion; that the curbstones acting as abutments support the arched pavement, and that it expands with the heat and rises from the concrete. To obviate this it was recommended that an expansion-joint of 1 inch or 1½ inches be left next the curb and filled with asphalt or paving-cement; also to lay expansion-joints filled with the same material across the street at regular intervals. It would seem, however, that if this trouble was caused by expansion, it would have taken place longitudinally along the street, as the width of the street is slight as compared to its length. This has occurred in one or two instances. It is reported that at Easton, Pa., when the temperature was 94° in the shade, a brick pavement was heaved to such an extent that it broke with a loud noise. The rupture formed an arch with a nine-foot span and an eight-inch rise extending from curb to curb, a distance of 42 feet.

An occurrence somewhat similar to this took place in Newark, N. J. Very few instances, however, have been reported, and in Brooklyn, N. Y., there is one street laid continuously with brick with a Portland-cement joint, a distance of ½ mile, where no trouble of this kind has occurred.

In 1895, however, two blocks of brick pavement were laid with the Mack block and Portland-cement joint. After the bricks were laid and had been rolled, the weather turned so cold that it was impossible for a while to do the grouting. When the weather became warmer, in attempting to roll further, it was found that

the bricks were so solidly imbedded in the frozen sand that many of them broke under the roller and the rolling was discontinued. An attempt was made to thaw out the frozen sand with hot water, but how thoroughly it was accomplished is uncertain. After the pavement had been laid for some time, a great deal of rumbling was observed when teams were driving over it, and many complaints were made by property owners. The bricks were cut out for a distance of 1½ inches along the curb on both sides, to see if that would relieve it, but no difference was noticed. A fifteen-ton macadam roller was run continuously over one block during an entire day in an attempt to press the brick down to a firm bearing. This caused no impression whatever upon the pavement, and the noise still continued as loud as before. So many and persistent were the complaints that the brick was finally taken up and replaced with asphalt. The other block, however, was not quite so noisy and is still in use, and no complaints are made by the property owners, and it seems as if the noise had decreased.

The theory of the city authorities was that there were slight local cavities existing between the brick and the concrete, caused by the frozen sand melting and shrinking somewhat. It is probable that an air-space of ⅛ of an inch, and perhaps even less than that, would cause this rumbling, and it would seem in this case as if the above were the proper solution. The argument against the expansion theory is that in many cases the noise is reported to have been greater during cold weather than warm.

There seems to be no question but that a brick pavement with its joints filled with a good cement grout will last materially longer than one with a less rigid filler, and if the pavement is laid during warm weather and care is taken to have the bricks thoroughly rolled and bedded in sand, there should be no trouble from abnormal noise. No trouble from noise has ever been experienced when sand or paving-cement has been used as a filler. If the foundation is not solid and is liable to settle unevenly, it would be a waste of money to use a rigid filler.

One objection to the rigid joint is the difficulty with which cuts are made in the pavement. Many bricks are broken in taking them up, and the expense of cleaning before relaying is considerable.

It is also hard to keep traffic of a small patch while the cement is setting.

A very large proportion off the early brick pavements in the West were laid entirely with sand joints, and experience there has shown that good brick will wear well under such conditions, but the pavement will not be impervious to water. When that is required a solid filler must be used; and if the engineers are afraid of noise from Portland-cement, a paving-cement filler can be used to advantage. If sand is used, it should be fine, silicious, and perfectly dry, so that it can be swept readily into the joints, so as to fill them completely and thus maintain the bricks in the position in which they are placed.

The bituminous should be applied at a temperature of from 250° to 300°, and if possible during the warm portion of the day when the bricks themselves are warm, so as to allow the cement to flow readily and completely fill the joints. This filling is sometimes applied by pouring the cement directly into the joints from buckets made for that purpose, or by spreading it indiscriminately over the surface and sweeping it into the joints with brooms. The objection to this latter method is that a certain amount of the cement is wasted and the entire surface of the pavement covered, which is liable to be sticky during the hottest part of the day. To obviate this last trouble, as soon as the joints are filled the pavement should be covered with a thin coating of sand, which under traffic will take up the cement and clean the surface to a certain extent. If the first covering should not do this satisfactorily, a second can be applied. This will also probably be necessary if the joints are filled from the buckets.

The grout, when Portland cement is used, is made by mixing equal parts of Portland cement and fine, sharp sand with sufficient water to give it such a consistency that it will readily flow into all the joints. Great care is necessary in this mixing both of the cement and sand, and also when the water is added, so that the grout shall be uniform in quality and not leave one joint in the bricks filled with almost pure cement and another with almost clear sand. The grout is generally mixed in large boxes, taking one barrel of cement at a time, and, after being thoroughly mixed, poured out upon the pavement and thoroughly broomed into

the joints. The street should be closed to traffic until the mortar of the joints is absolutely and entirely set, which will probably require a week and perhaps more; but it is very important that it be thoroughly hardened before any traffic is allowed upon it.

There is probably less difference in the practice of the cities in laying brick pavements than in any other kind, and this is undoubtedly due to the work of the National Paving Brick Manufacturers' Association, which has made a great many experiments to determine not only what proper and necessary tests should be made to determine what would be a good brick, but also the detail method by which the pavement should be laid. This association has also maintained a paid secretary, whose duty it has been to disseminate the results of these experiments and in various parts of the country to work for the best brick pavements that could be laid. In former years it was deemed necessary to make crushing tests, cross-breaking tests, absorption tests, etc., of the bricks, but in the specifications recently put forth by the National Paving Brick Manufacturers' Association, the American Society of Municipal Improvements and the Organization for Standardizing Paving Specifications, none of these tests is required, these organizations feeling that if the bricks would sustain the abrasion test they would of necessity pass what other tests might be instituted for the other properties referred to. This result was doubtless arrived at after the elaborate tests made, at the instance of the National Brick Manufacturers' Association,* by men peculiarly adapted for the work, and the results of which were furnished to the association several years ago.

At the same time, however, some engineers still maintain absorption tests. For instance, the City of St. Louis in its specifications provides that the brick shall not absorb more than 2 per cent of water after being immersed for 48 hours, provided, however, that an absorption of not exceeding 4 per cent may be allowed in case the brick will show a loss of weight by abrasion of not over 20 per cent of the original weight of the brick, the

* A different organization from the National Paving-Brick Manufacturers' Association.

absorption test to be made on brick that has been broken and passed through the rattler.

The City of Cincinnati provides that the brick shall be thoroughly dried, broken in two and immersed in water for 48 hours, with the gain in weight must not be over 3 per cent.

The City of Cleveland provides that the brick shall be baked for 24 hours and then immersed in water for 48 hours, and no brick accepted that absorbs more than 4 per cent of its weight, and no more than one-third of the accepted brick shall absorb more than 3 per cent.

Although there is no very material difference in the specifications of the three organizations referred to, and none at all in those of the American Society of Municipal Improvements and the Organization for Standardizing Paving Specifications, still there is some between these last two organizations and the specifications of the National Paving Brick Manufacturers' Association. The latter provides that the size of the brick shall not be less than 2½ by 4 by 8 inches, nor more than 3¾ by 4 by 9½ inches; the former two provide that the standard size of the brick shall be 2½ by 4 by 8½ inches and the standard size of the block 3½ by 4 by 8½ inches. An allowance is made for slight variations in all of these dimensions.

The two associations referred to provide that all brick shall be laid on a concrete base, while the Manufacturers' Association refers to a report made by Prof. Baker which stated that a foundation constructed of No. 2 paving block with grouted joints possessed greater strength than a 6-inch concrete base, so that that association permits the use of either a No. 2 paving-block foundation or a concrete foundation. All three organizations provide that the brick shall be laid upon a cushion of sand spread upon the surface of the pavement, but while the two organizations provide that the depth of the cushion shall be 1½ inches, the Manufacturers' Association calls for 2 inches. This may seem a small point, but it is one upon which the Manufacturers' Association is very insistent and urges that this depth must be used in every case in order to produce the best result, giving as a reason that this depth not only relieves the pavement from the effects of vibration and injury to the brick or the shattering of the cement

filler, but that it has sufficient thickness to be maintained in compression against at least the less severe frost action from below the foundation and prevents cracks in the pavement that might otherwise happen with a sand cushion an inch or less in depth. Most engineers, however, deprecate this practice and many of them advocate a cushion as thin as 1 inch. The object of the cushion is mainly to insure a firm bed and even bearing to the brick, and if the concrete is made smooth it would seem that this could be accomplished by a less amount than 2 inches and that that 1½ inches would be sufficient. Very few engineers use more than this amount.

All of three specifications provide that an expansion joint shall be provided parallel with and next to the curb. The Manufacturers' Association call for a 1-inch width for streets 30 feet and less in width and 1½ inches for streets wider than 30 feet, while the other two organizations call for 1½ inches for all streets.

Probably the point in construction of brick pavements upon which there is greatest variation in the ideas of different engineers is that of the filler for the joints between the bricks. While in the early days of brick pavements the joints were often filled with sand, that practice has been almost entirely abandoned at the present time and a Portland cement grout or a bituminous filler used. The Manufacturers' Association provides that the filler shall be cement grout composed of 1 part of clean, sharp, fine sand and 1 part of Portland cement; the other two associations, while providing a specification for the cement grout filler, also provide one for coal tar paving pitch filler and also for an asphalt filler.

This question was also discussed at considerable length at a meeting of the American Society of Civil Engineers held in New York in January of 1912. The advocates of the grout filler argued that by its use the pavement would be practically a monolith and that the wear would be scarcely perceptible, but what there was would be even and for that reason the pavement would last longer. It was also claimed that the cement filler would prevent the bricks chipping at edges, which was liable to occur with a soft filler, and also that the grout-filled pavements were more sanitary than the others. It was stated that at Columbus, O.,

soft fillers were used until about 1910, since which time the grout filler had been used; also, that Cleveland had used grout fillers almost exclusively for 15 years for both stone and brick pavements with satisfactory results.

It was also claimed by the advocates of a soft filler that if the brick were of the right quality they would not chip at the edges and that if a proper amount of bituminous filler were used the brick pavement would be practically noiseless and more free from dust than with the cement filler. It should be noted here that some of those who argued for the cement filler also claimed that it would be less noisy than with a soft filler.

It was also argued in favor of the soft filler that a street could be opened for traffic immediately after the pavement was completed, while with the cement filler it was necessary to keep the street closed from 7 to 10 days until the cement had thoroughly set. Both sides of the question were argued at length and forcibly by the engineers from different sections of the country, and it would seem to be a logical conclusion from the arguments made that first-class pavements could be laid with either filler when the work was properly done with the proper materials. The author, however, has always felt that if a cement filler was properly used the pavement would last longer than with a soft filler, although it would probably be more noisy.

The specifications of the two organizations provide that when a brick pavement is laid next to street-car tracks the brick should not be laid within $\frac{1}{4}$ of an inch of the rail, and that when it was rolled to its permanent bearing it should be $\frac{1}{4}$ of an inch below the top of the rail. This latter point was argued at considerable length at the New Orleans meeting, and many of the engineers believe that the rail should not be above the finished pavement. The main argument for leaving the pavement below the rail seemed to be that the track would probably settle while the pavement would not, and if the pavement were laid flush with the rail, in a short time, on account of the settlement of the track, it might be above, which would not be advisable.

Abrasion Test.

While the abrasion test was used to determine the quality of paving brick for many years, it was a long time before the test itself was standardized. The testing was done with different materials and different machines, so that the results of one test could not be properly compared with those of another. This matter was gone into very thoroughly and carefully by the National Paving Brick Manufacturers' Association, and the specifications which follow were adopted as a result of those tests. The Manufacturers' Association specifies that if the abrasion test is required, the brick shall be tested under the specifications in manner and method and with a rattler, together with a record thereof, as adopted by the National Paving Brick Manufacturers' Association at its annual meeting of 1911. The other two organizations specify that tests shall be made giving in detail the construction of the rattler, the charge that shall be placed in same, and the method of making the test. They specify that the blocks shall not lose their weight more than 22 per cent for a heavy, 26 per cent for a medium and 28 per cent for a light traffic street, after having been submitted to the tests. They also say that as the committee has not made any tests with the brick size they do not recommend what the abrasion loss shall be. This can easily be determined, however, by testing several samples of well-known bricks and by observing and comparing the results. The requirements made for the blocks are the results of tests made by the committee.

The specifications adopted by the National Paving Brick Manufacturers' Association for the rattler test as referred to previously, are herewith given. They were adopted at Grand Rapids and at New Orleans by the two other organizations.

"*The Rattler.*—The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame and driving mechanism as herein described.

"*The Barrel.*—The barrel of the machine shall be made up of the heads, headliners and staves.

"The heads shall be cast with trunnions in one piece. The

trunnion bearings shall not be less than two and one-half (2½) inches in diameter or less than six (6) inches in length.

"The heads shall not be less than three-fourths (¾) inch thick nor more than seven-eighths (⅞) inch. In outline they shall be a regular fourteen-sided (14) polygon inscribed in a circle twenty-eight and three-eighths (28⅜) inches in diameter. The heads shall be provided with flanges not less than three-fourths (¾) inch thick and extending outward two and one-half (2½) inches from the inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two (2) three-fourths (¾) inch bolts at each end of each stave, said slots to be thirteen-sixteenths ($\frac{13}{16}$) inch wide and two and three-fourths (2¾) inches centre to centre. Under each section of the flanges there shall be a brace three-eighths (⅜) inch thick and extending down the outside of the head not less than two (2) inches. Each slot shall be provided with recess for bolt head, which shall act to prevent the turning of the same. There shall be for each head a cast iron headliner one (1) inch in thickness and conforming to the outline of the head, but inscribed in a circle twenty-eight and one-eighth (28⅛) inches in diameter. This liner or wear plate shall be fastened to the head by seven (7) five-eighths (⅝) inch cap screws, through the head from the outside. These wear plates, whenever they become worn down one-half (½) inch below their initial surface level, at any point of their surface, must be replaced with new. The metal of which these wear plates are to be composed shall be what is known as hard machinery iron, and must contain not less than one (1) per cent of combined carbon. The faces of the polygon must be smooth and give uniform bearing for the staves. To secure the desired uniform bearing the faces of the head may be ground or machined.

"*The Staves.*—The staves shall be made of six (6) inch medium-steel structural channels twenty-seven and one-fourth (27¼) inches long and weighing fifteen and five-tenths (15.5) pounds per lineal foot.

"The channels shall be drilled with holes thirteen-sixteenths ($\frac{13}{16}$) inch in diameter, two (2) in each end, for bolts to fasten same to head, the center line of the holes being one (1) inch from

either end and one and three-eighths ($1\frac{3}{8}$) inches either way from the longitudinal centre line.

"The space between the staves will be determined by the accuracy of the heads, but must not exceed five-sixteenths ($\frac{5}{16}$) inch. The interior or flat side of each channel must be protected by a lining or wear plate three-eighths ($\frac{3}{8}$) inch thick by five and one-half ($5\frac{1}{2}$) inches wide by nineteen and three-fourths ($19\frac{3}{4}$) inches long. The wear plate shall consist of medium steel plate, and shall be riveted to the channel by three (3) one-half ($\frac{1}{2}$)-inch rivets, one of which shall be on the centre line both ways and the other two on the longitudinal centre line and spaced seven (7) inches from the centre each way. The rivet holes shall be countersunk on the face of the wear plate and the rivets shall be driven hot and chipped off flush with the surface of the wear plate. These wear plates shall be inspected from time to time, and if found loose shall be at once reriveted, but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than one hundred and fifty (150) tests under any circumstances. The record must show the date when each set of wear plates goes into service and the number of tests made upon each set.

"The staves when bolted to the heads shall form a barrel twenty (20) inches long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four (4) three-fourths ($\frac{3}{4}$) inch bolts, and each bolt shall be provided with lock nuts, and shall be inspected at not less frequent intervals than every fifth (5th) test and all nuts kept tight. A record shall be made after each such inspection, showing in what condition the bolts were found.

"*The Frame and Driving Mechanism.*—The barrel should be mounted on a cast-iron frame of sufficient strength and rigidity to support same without undue vibration. It should rest on a rigid foundation and be fastened to same by bolts at not less than four (4) points.

"It should be driven by gearing whose ratio of driver to driven should not be less than one (1) to four (4). The counter shaft upon which the driving pinion is mounted should not be

less than one and fifteen-sixteenths ($1\frac{15}{16}$) inches in diameter, with bearings not less than six (6) inches in length and belt driven, and the pulley should not be less than eighteen (18) inches in diameter and six and one-half ($6\frac{1}{2}$) inches in face. A belt of six (6) inch double-strength leather, properly adjusted, so as to avoid unnecessary slipping, should be used.

"*The Abrasive Charge.*—(*a*) The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be three and seventy-five-hundredths (3.75) inches in diameter when new and shall weigh when new approximately seven and five-tenths (7.5) pounds (3.40 kilos) each. Ten shall be used.

"These shall be weighed separately after each ten (10) tests, and if the weight of any large shot falls to seven (7) pounds (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of the large shot shall not be discarded and substituted by new ones at any single time, and that so far as possible the large shots shall compose a graduated series in various stages of wear.

"The smaller size spheres shall be, when new, one and eight hundred seventy-five-thousandths (1.875) inches in diameter and shall weigh not to exceed ninety-five-hundredths (.95) pounds (0.430 kilos) each. Of these spheres so many shall be used as will bring the collective weight of the large and small spheres most nearly to three hundred (300) pounds, provided that no small sphere shall be retained in use after it has been worn down so that it will pass a circular hole one and seventy-five-hundredths (1.75) inches in diameter, drilled in a cast-iron plate one-fourth ($\frac{1}{4}$) inch in thickness or weigh less than seventy-five hundredths (.75) pounds (or .34 kilos). Further, the small spheres shall be tested by passing them over such an iron plate drilled with such holes, or shall be weighed after every ten (10) tests, and any which pass through or fall below specified weight, shall be replaced by new spheres, and provided, further, that all of the small spheres shall not be rejected and replaced by new ones at any one time, and that so far as possible the small spheres shall compose a graduated series in various stages of wear. At any time that any sphere is found to be broken or defective it shall at once be replaced.

(*b*) The iron composing these spheres shall have a chemical composition within the following limits:

" Combined carbon—Not less than 2.50 per cent.
" Graphitic carbon—Not more than 0.10 per cent.
" Silicon—Not more than 1 per cent.
" Manganese—Not more than 0.50 per cent.
" Phosphorus—Not more than 0.25 per cent.
" Sulphur—Not more than 0.08 per cent.

" For each new batch of spheres used the chemical analysis must be furnished by the maker, or be obtained by the user, before introduction into the charge, and unless the analysis meets the above specifications, the batch of spheres shall be rejected.

" *The Brick Charge.*—The number of brick per charge shall be ten (10) for all bricks of the so-called ' block size ' whose dimensions fall between from eight (8) to nine (9) inches in length, three (3) and three and three-fourths (3¾) inches in breadth and three and three-fourths (3¾) and four and one-fourth (4¼) inches in thickness. No block should be selected for test that would be rejected by any other requirements of the specifications.

" The brick shall be clean and dried for at least three (3) hours in a temperature of one hundred (100) degrees Fahr. before testing.

Speed and Duration of Revolution.—The rattler shall be rotated at a uniform rate of not less than twenty-nine and one-half (29½) nor more than thirty and one-half (30½) revolutions per minute, and eighteen hundred (1800) revolutions shall constitute the standard test.

" A counting machine shall be attached to the rattler for counting the revolutions. A margin of not to exceed ten (10) revolutions will be allowed for stopping. Only one (1) start and stop per test is regular and acceptable.

" *The Results.*—The loss shall be calculated in percentage of the original weight of the dried brick composing the charge. In weighing the rattler brick any piece weighing less than one (1) pound shall be rejected.

Report of Standard Rattler Test of Paving-bricks.

IDENTIFICATION DATA.

Serial No. (   )

Name of the firm furnishing sample..
Name of the firm manufacturing sample ....
Street or job which sample represents.....................................
Brands or marks on the brick ....
Quantity furnished ....Drying treatment.......
Date received...................................Date tested...........
Length...............................Breadth.......Thickness.......

STANDARDIZATION DATA.

Number of charges tested since last inspection..........................

Weight of Charge (After Standardisation).	Condition of Locknuts on Staves.	Condition of Scales.
10 Large spheres............		
Small spheres............		
Total...............		

Number of charges tested since stave linings were renewed................
Repairs (Note any repairs affecting the condition of the barrel)............

RUNNING DATA.

Time Readings.				Revolution Counter Readings.	Running Notes, Stops, etc.
	Hours.	Minutes.	Seconds.		
Beginning of test.					
Final reading....					

WEIGHTS AND CALCULATIONS.

		Percentage loss (Note.—The Calculation Must Appear.)
Initial weight of 10 bricks....		
Final weight of same........		
Loss of weight.............		

Number of broken bricks and remarks on same.........................

I certify that the foregoing test was made under the specifications.....
.... of ....and is a true record.

Signature of ....
(Tester)

Date......................Location of Laboratory.................

Records.—(*a*) The operator shall keep an official book, in which the alternate pages are perforated for removal. The record shall be kept in duplicate, by use of a carbon paper between the first and second sheets, and when all entries are made and calculations are completed the original record shall be removed and the carbon duplicate preserved in the book. All calculations must be made in the space left for that purpose in the record blank, and the actual figures must appear. The record must bear its serial number and be filled out completely for each test, and all data as to dates of inspection and weighing of shot and replacement of worn-out parts must be carefully entered, so that the records remaining in the book constitute a continuous one. In event of further copies of a record being needed, they may be furnished on separate sheets, but in no case shall the original carbon copy be removed from the record book.

"(*b*) The blank form upon which the record of all official brick tests is to be kept and reported is given on page 323."

Laying the Brick.

After the concrete has become sufficiently set it should be covered with a sand cushion, care being taken to see that the sand is entirely free from any small stones or pebbles that might cause the brick to be supported unequally. The sand is brought to the exact shape desired by means of a template which has been cut to the required crown, resting on the curbs if the roadway be narrow, or, if too wide for that method, with one end resting on the curb and the other on a scantling buried in the sand at the centre. After one side is brought to the desired shape the template can be reversed and used on the other side. No walking on the prepared surface, or disturbance of it of any kind, should be allowed. The pavers, unlike stone-pavers, should stand on the completed pavement, working from themselves. The courses should always be started with a half-brick, so as to break the joints evenly across the street, and when finished they should be set up tightly with an iron bar so that the end joint shall be as close as possible.

This is important, whatever the joint-filler is, as these cross-

joints come directly in the line of travel. The courses should be kept square with the street and trued up every four or five feet. It is customary generally to have one man working at the side of a street where the courses are complèted, cutting the brick to be used as closers. After the brick have been laid, the surface should be swept off clean and, if a steam-roller is to be had, should be thoroughly rolled until all the brick are brought to a firm and even bearing. If the brick run unevenly for hardness, it may be desirable, just previous to rolling, to wet the pavement thoroughly with a hand-hose, so that the soft bricks can be detected. This is a sure test, as the soft brick absorb the water readily, and when the harder ones dry those retaining the moisture can easily be seen and should be removed and others put in their places.

If a steam-roller cannot be had, good results can be obtained by ramming, when a plank should be laid on the surface parallel to the curb-lines, and the pavement rammed by striking the plank with an iron rammer. If the planking is used crosswise of the street, the pavement is liable to be rammed unevenly. The principles laid down in the stone pavement for the position of the bricks and direction of the courses, both between streets and at intersections, are perfectly applicable to brick. The method shown in Fig. 57, called the herringbone plan, is sometimes used. This, however, is not desirable, as between the streets it brings the line of cross-joints lengthwise to the travel of the street, which permits a weak spot in the pavement, and at intersections it brings a great many of the brick lengthwise of the traffic turning the corners. This method has never been used to any great extent. Brick pavements, especially when laid with a sand filler, generally show considerable wear during the first few weeks, especially if laid with rectangular bricks rather than those with rounded edges. This is because the traffic quickly finds any inequalities in the surface, and also because the horses' shoes soon round off the edges of the softer brick; but in a short time this abnormal wear ceases, and from then on the observable wear is slight.

CHAPTER X.

WOOD PAVEMENTS.

Without doubt the crudest and probably the earliest form of a wooden roadway was that which is generally known as the corduroy road. This was constructed roughly by laying logs cut to the desired length across the roadway in close contact with each other. This construction was used at low places in roads across swamps, and, while being very rough and uncomfortable, was fairly serviceable and made many of the roads passable which, without this, could not have been used for a considerable portion of the year. This form of roadway is in use now to a limited extent on wood roads in certain parts of New England.

In Alpena, Mich., roadways, and even entire streets, have been graded with sawdust, while in other parts of the State roads have been constructed of charcoal. The method was to pile logs along the road two or three feet high, and burn them in practically the position in which the material was to be used. After the coal was burned, it was raken off and graded down to the required width and depth of the road. This construction gave very good satisfaction, and in 1845 the Commissioner of Patents in his report stated that at the season when the mud in an adjoining road was half-axletree deep, on the coal road there was none at all, and the impress of the feet of horses passing rapidly over it was like that made on hard-washed sand as the surf recedes on the shore of a lake.

Russia, however, is reported to have had the first real wooden pavements, as hexagonal blocks are said to have been in use there several hundred years ago. They could not have been used to any great extent or for any great length of time, as no detailed record is obtainable of them.

In London, Eng., the first wooden pavement was laid in 1839.

This consisted of hexagonal blocks of fir, some 6 to 8 inches across and 4 to 6 inches deep. They were laid on a foundation of gravel that had been previously compacted. The blocks were either bevelled on the edges or grooved on the face to afford foothold for the horses. These first pavements were not very successful, but others soon followed. Mr. Hayward, the engineer of the Sewer Commission, stated in a report made in 1874 that, counting the size of blocks as constituting the difference, there must have been more than two dozen different kinds of wood pavements experimented with in the city previous to that time.

Another system known as Carey's consisted of blocks 6½ to 7½ inches wide, 13 to 15 inches long, and 8 or 9 inches deep, the sides and ends having projecting and re-entering angles, locking the blocks together to prevent unequal settlement. Pavements of this kind were laid in 1841 and 1842. They required renewing every three or four years. The dimensions of the blocks were afterwards modified and finally reduced to a width of 4 inches and a depth of 5 or 6 inches, and the re-entering angles were also discarded.

Another system, known as Improved Wood, was first adopted in 1871. On a subgrade a bed of 4 inches of sand was laid, and upon that two layers of inch deal boards, saturated with boiling tar, one layer across the other. The blocks were 3 inches wide, 5 inches deep, and 9 inches long. They also were dipped in tar and laid on the boards with the end joints closed, but the transverse joints were ¾ of an inch wide, the space being maintained by pieces of boards nailed to the foundation and also to the blocks. The joints were filled with gravel, rammed, then a composition of pitch and tar was poured in until the joints were completely filled, when the surface was also covered with tar, gravel, and sharp sand. This foundation was somewhat elastic and maintained the even surface of the pavement as long as it was in shape, but when the pavement became pervious to water it settled and became rough and uneven. This was probably the first use of the tar and gravel joint for pavements of any description.

In 1872 a cement-concrete foundation was first used for a wood pavement. The concrete was 4 inches thick and was laid by the Ligno Mineral Co. The blocks were of beech, mineralized by a special process, 3½ inches wide, 4½ inches deep, and 7½ long, with

the ends cut to an angle of 60°. They were laid with the ends inclining in opposite directions in alternate courses. In a few years, however, this form of block was abandoned for the rectangular, and fir was used instead of beech. The blocks were bedded in Portland cement and laid with joints ¼ inch wide, partly filled with asphalt, and then grouted with mortar. It was thought after a few years' experience that the laying of the blocks directly upon concrete made so rigid a construction that the blocks wore more rapidly under traffic than they otherwise would. There were several means devised for overcoming this and making the pavement more elastic. The Asphalt Wood Paving Co. laid ½ inch of asphalt upon concrete, and formed also the lower part of the joint with the same material, and the upper part with a grout of Portland cement and gravel. In addition to the elasticity, it was claimed that this also gave a perfectly water-tight joint. One objection to this method, however, was that the asphalt softened under blocks when the weather became hot, allowing them to settle unevenly under traffic, making the pavement generally uneven and consequently causing abnormal wear.

Still another system was what was known as Henson's. In this method the blocks were laid close, with a strip of roofing-felt from $^1/_{16}$ to $^1/_8$ of an inch thick, cut to the same width as the depth of the blocks, laid between each course. The joint was thus closed as completely as possible, leaving only the actual fabric of the felt, the material support of the blocks saving them from the rapidly destroying action of spreading at the edges. The protection of the wood was further enhanced by a layer of similar felt over the whole surface of the concrete foundation upon which the wooden blocks were cushioned. Another object of laying the felt between the blocks was to take up any longitudinal expansion that might occur on account of the changes of the atmosphere. It was thought that the felt would be thick enough to provide for the expansion of any one course of blocks. The results justified this method, which was somewhat expensive, but the endurance of the blocks was said to be increased from one-half to two-thirds by this freedom from the joining of the blocks and the mutual support of the edges. In order to provide for the transverse expansion a space of 1 or 1½ inches was left along by the curb and

filled with asphalt, sand, or gravel. In some cases, however, the row of blocks next to the curb was left open until the greatest amount of expansion had taken place, and then filled in.

The kind of wood used in London at that time was generally Swedish deal, and the blocks were generally laid without any chemical treatment, as that was considered of doubtful advantage, as they wore out under traffic rather than failed from decay, and it was not thought that creosoting or similar treatment would benefit the wearing qualities.

In 1874 Mr. Wm. Haywood made an extensive report to the Commissioners of Sewers of London upon the comparative merits of wood and asphalt pavements. At that time there were but 12,238 square yards of wood pavement and 30,802 square yards of asphalt, quite a portion of the area previously laid with wood having been replaced with asphalt.

In a table which he presented at that time he gave the actual life of wooden pavements that had been laid at different times since 1841 as varying from five years and five months to nineteen years and one month. The pavement having the longest life, strangely enough, was the first one laid of those in the table. The average cost per square yard during life, including repairs, varied from 1s. 5½d. to 3s. 4d., which last pavement had a life of twelve years and three months. He gave the average life of the pavements in the three streets of the largest traffic as nine years, and those of the least traffic as eleven years and three months. His conclusions on the whole were more favorable to asphalt than to wood, although the experience with asphalt at that time extended over a period of only five years, but later experience has justified his conclusions. London at the present time is using wood as a paving material practically for the same reasons as those given for Paris—because it is less noisy than stone and less slippery than asphalt.

On London Bridge, King William Street, blocks wore 2⅝ inches in three years and two months, the traffic being 12,000 vehicles per yard for twelve hours. Mr. Haywood estimated in general that the wear of wooden pavements would be from $^2/_{10}$ to $^3/_{10}$ of an inch per year, under traffic of from 300 to 660 vehicles per yard for twelve hours.

In 1884 the wood pavements in London consisted generally of blocks 3 inches wide by 6 inches deep by 9 inches long, although the dimensions of length and depth varied somewhat.

Swedish deal blocks laid on concrete with a cushion-coat of asphalt cost \$3.08 per square yard and had an average life of seven years and cost \$0.209 annually for repairs. Creosoted blocks, lime joints, cost \$2.95 per square yard, with an average life of eight years, and cost \$0.204 per year for repairs. Creosoted blocks with asphalt mastic joints cost \$3.55 per yard, with an average life of eight years, and cost \$0.24 per year for repairs. Pitch-pine blocks cost \$2.91 per square yard, with cement joints, with a life of eight or nine years, and were maintained at an expense of \$0.088 per square yard per year for repairs. The life of these foreign pavements is estimated for the traffic standard of 750 tons per yard of width per day.

The cost of repairs varies very much with the method of making them. A contract was made to keep Piccadilly and part of Kings Road in repair for fifteen years for 3s. per yard per year, when the engineer estimated that its cost would not be more than 2s. The annual cost per square yard for a plain deal, spread over fifteen years, ran 1s. $3\frac{3}{4}$d., with a traffic of 279 tons, to 3s. 2d. for improved pitch-pine, with a traffic of 558 tons per yard per day. These figures were made in 1884. In 1893 a portion of the Euston Road was paved with wood—63 feet with yellow deal, 62 with Karri, 49 with yellow deal, and 63 with Jarrah. After three years' time the wear was found to be $\frac{1}{4}$ inch on Jarrah and Karri, and $1\frac{3}{8}$ inches on the deal. From observations taken, the traffic was found to be 575,544 tons per yard of width per annum. On another portion of the same road the wear was $\frac{1}{8}$ inch per annum with a traffic of 411,318 tons.

Tottenham Court Road, which was paved with Jarrah blocks, showed only $\frac{1}{4}$ inch of wear after three years, with greater traffic than Euston Road, and on the Westminster Bridge Road after nearly seven years of wear the Jarrah blocks had worn from $1^1/_{16}$ to $1^1/_8$ inches, with a traffic of from 233 to 334 tons per foot of roadway in twelve hours.

Table No. 64 gives information relative to hard-wood pavements in London.

TABLE No. 64.

Parish or District.	Kind of Wood.	Approximate Area. Square Yards.	First Cost and Cost of Renewal. Inclusive of Excavations and Foundations.	First Cost and Cost of Renewal. Exclusive of Excavations and Foundations.	Average Life under Ordinary Conditions. Years.	Average Life under Heavy Traffic. Years.	Remarks.
Fulham	Jarrah	542	4.50	......	......	....	Complaints as to slipperiness.
Holborn........	"	2262	......	......	......	....	Laid eighteen months.
Islington.....	Jarrah, Karri, BlueGum	27000	......	2.83 to 3.18	...	..	Baltic deal not entirely superseded.
Lambeth.....	Jarrah, Karri, BlueGum	120000	3.40 to 3.50	2.54 to 2.62	....	..	The vestry buys material and does its own sawing, with apparently economical results. The surveyor reports favorably.
Poplar.....	....	....	.. ..	......	......	..	Insufficient experience.
St. George, Hanover Sq.	Karri	....	......	.. ...	......	..	Small trial strip only. Surveyor prefers deal.
St. George the Martyr..	Jarrah	23000	3.50	....	15to 20	10	Hardwood first adopted in 1898. Soft wood now abandoned.
St. Martin-in-the-Fields...	Jarrah, Karri	8450	......	2.75	12½	12½	
St. Pancras..	Jarrah, Karri, BlueGum	110000	......	2.62 to 2.87	....	..	Hardwood will probably be extensively used in this parish.
Wandsworth	Jarrah, Karri,	18000	4.12	......	9	7	It is not proposed to increase the use of hardwood to any great extent.
Kensington..	Jarrah, Karri	3509	......	.. ..	.....	..	Not satisfactory.

Hardwood paving has not been sufficiently long in use to judge accurately as to its life under varying conditions, but generally it would appear to last about twelve years. The Council in granting loans of this kind allows a period of ten years for the repayment thereof. For heavy traffic the material is likely to be extensively used, although in several districts Baltic deal is still employed in preference, the average cost of the latter being $1.68 per square yard, and the life from five to eight years.

NOTE.—The above information concerning hardwood pavements in London was furnished the author by the Clerk of the Council in 1899.

London County Council Specifications.

Soft-wood Pavements.—White or soft wood paving shall be of new wood blocks, 5 inches deep by 9 inches long by 3 inches wide, cut out of fresh Swedish or White Sea yellow wood known as red deal, of the quality equal to Gothenburg seconds, Gefle or Soderham fourth yellows (spruce, hemlock or "whitewood" will not be accepted).

It must be of a heavy resinous nature with not more than 15 per cent of bright sapwood and with the light or spring growth rings nor unduly larger than the dark or autumn growth rings. Blocks showing blue sap or discolored wood will not be accepted.

The blocks must be cut perfectly true in shape and size of the full specified depth after sawing and free from large, loose or dead knots, waney edges, warps, shakes and other defects. One surface of every block must be free from knots.

The blocks are to be creosoted, the temperature of the oil being not less than 150° F., the creosote to be forced into the blocks at a pressure of not less than 80 pounds to the square inch, and to the extent of 10 pounds of oil to the cubic feet of timber. Before applying the pressure the cylinder is to be exhausted to a vacuum equivalent to 20 inches of mercury.

The creosote is the oil of tar known as creosote oil, free from all adulteration and impurities, generally free from ammoniacal water and containing not less than 5 per cent of crude coal tar acids. The specific gravity is to range between 1.035 and 1.060 (water being 1.000) at a temperature of 60°. It is not to deposit anything when kept at a temperature of 50° F. for 3 hours.

The quantity of creosote in the blocks will be ascertained by weighing 100 blocks before being put in the cylinder, and again weighing the same blocks after the creosoting process is completed.

The engineer or his representative will have full power to enter upon the contractor's works at any time to see the process of cutting and creosoting and to reject any blocks that he may consider unsuitable for the purpose. No blocks are to undergo the creosoting process until they have been approved by the engineer or his assistant.

The engineer shall be at liberty to take samples of the creosote oil for analysis and should the oil not be to his satisfaction the whole of the blocks creosoted with such oil may be rejected.

Notwithstanding the engineer's or his representative's examination of the blocks at the contractor's works, the engineer shall have full power to reject any blocks on the site of the works if in his opinion they are not in accordance with the specification as regards size, shape, knots, shakes or creosoting. Blocks so rejected shall be immediately removed.

Hardwood Pavements.—" Hardwood " paving shall be of well-seasoned close-grained Australian hardwood equal in quality to the best Karri or Jarrah, free from all knots, shakes, fungus or other defects. The blocks must measure 9 inches long by 3 inches wide by 5 inches deep after sawing and must be cut perfectly true in shape.

The engineer or his representative will have full power to enter on the contractor's works at any time to see the process of cutting the blocks and to reject any which he may consider unsuitable; and notwithstanding such examination, the engineer shall have full power to reject any blocks when delivered on the site of the works if in his opinion they are not in accordance with the specification as regards size, shape or quality of wood. Blocks so rejected shall be immediately removed.

The entire area under the wood paving, and the adjacent curbs, shall be formed of Portland cement concrete, of the depth shown on the drawings, and shall be properly floated on the top with fine stuff. The whole of the concrete to be composed of Portland cement and ballast in the proportions and otherwise as shown on the drawings. The fine stuff for the floating to be composed of one of cement to five of sand, and the surface to be properly ruled and finished off and left hard and smooth. When the concrete foundation has been properly formed and has thoroughly set, the space between the curbs is to be paved with wood as hereafter described. In any case, even if the concrete has set, a period of at least 4 days should be allowed to elapse before the wood blocks are laid down on the concrete. As soon as the concrete foundation is thoroughly set to the satisfaction of the engineer, the blocks are to be laid upon its surface in rows at right angles to or radiated across the street. At each side of the carriageway two courses are to be laid longitudinally (a suitable margin, 1 inch or 2 inches wide, filled in with approved clay or sand, being left next the curb stone to allow for swelling). The blocks at all intersections of streets are to be laid with proper angle courses.

The wood paving shall be laid with close joints, run in with pitch and tar to the engineer's approval, and as he may direct.

The contractor must not use old creosoted blocks for fuel for the tar boilers, which must be suitable for burning coke.

The paving is to be then brushed over with 5 to 1 cement grout so that all the joints are properly filled. Upon the surface a top dressing 1 inch in thickness of fine ballast is to be spread, after which the traffic is to be fenced off for 6 days. When the wood paving abuts against any macadam road a double course of approval granite setts (grouted) is to be laid on concrete along the whole length of the joint, between the wood pavement and the macadam. The concrete under the wood paving shall be continued on to form the bed for the pitching and shall project at least 3 inches beyond the pitching.

Unless the blocks are laid with close joints, as specified above, small strips of wood shall be employed for keeping a uniform joint, into which the bonding material can be filled.

Westminster, London.

Wood Blocks.—The whole of the timber, both soft and hard, to be good sound timber, well seasoned, and sufficiently matured. No block to contain more than 10 per cent of sap wood, and all blocks to be free from shakes, waney edges, warps, sneaps, large, loose or dead knots, or other defects, and to be sawn square and true.

Brands or Marks of Timber and Ports of Shipment to be Stated.—All softwood blocks shall be cut from good quality pine deals from Baltic, White Sea or Archangel Ports. Tenderers shall state in the space provided in the accompanying schedule the brands or marks and the port of shipment of the timber they propose to supply.

Size of Wood Blocks.—No wood block shall be less than 8 inches or more than 9½ inches in length or less than 3 inches or more than 3½ inches in width. Each block shall be exactly the depth ordered, as no allowance will be made for the saw cut.

Creosoting Wood Blocks.—The whole of the softwood blocks used in the work shall be thoroughly impregnated with pure creosote oil, free from all ammoniacal water, and containing not less than 8 per cent of tar acids. The wood blocks shall be

creosoted by Boulton's or Bethell's process, the temperature of the oil in the cylinder being not less than 220° F., the cylinder to be first exhausted to a vacuum equivalent to 20 inches of mercury, and the creosote then forced into the blocks to the extent of not less than 10 lbs. to the cubic foot of timber. The quantity of creosote in the blocks shall be ascertained by weighing 50 blocks of each charge in the white, and after creosoting, the same 50 blocks shall be wiped, and all moisture adhering to their surfaces removed. The blocks shall then be weighed, and the difference between the weight so ascertained and the weight of the same blocks in the white shall be taken as the weight of the creosote oil absorbed.

Setting of Foundation.—After the foundation has been finished, the blocks shall not be permanently laid upon it for at least 6 days without special permission of the engineer, during which time the concrete shall be protected from the weather and any injury, but wood blocks shall be "headed up" as provided in the next clause.

Laying Wood Blocks.—All pavements composed of wood blocks shall be laid as follows: Two courses of hand-dipped blocks shall be laid on each side of the road parallel to the curb, and a space of from 1 to 2 inches, if required by the engineer, shall be left between the curb and the wood blocks, to allow for expansion, such space to be filled in with clean puddled clay, or other approved material. The portion of the road between these courses shall be laid with blocks at right angles to the direction of the road, except at the intersection of other roads, where the blocks shall be laid diagonally as directed. After the concrete and floating coat has been in position three days, the wood paving blocks shall be "headed up" on the foundation and shall so remain for three further days before the blocks are "laid" permanently. No blocks shall be laid until they have been so "headed up" for three days. All pavements shall be laid so as to leave as little space as possible at the sides and ends of the blocks, and on completion a mixture of boiling pitch and creosote oil in approved proportions shall be poured over the whole surface and well forced into the joints, and scraped off with wooden or rubber squeegees, the joints being thoroughly filled. The pavement shall then be

finished with fine sand and cement grout in equal proportions brushed over, and with a top dressing of approved gravel to pass a ½-inch mesh free from sand. Care shall be then taken that not more than sufficient grout is used; in the event of it "spewing" in hot weather, or working up under traffic, the contractor shall be required to remove the surplus and cleanse the road surface at his own cost.

Hardwood blocks (Jarrah and Karri) shall be hand-dipped on one side in an approved mixture of boiling pitch and creosote oil immediately before laying, and shall be laid with as tight a joint as possible, the paving afterwards being grouted over and finished off in all respects as above specified.

No wood paving of any kind is to be grouted over without special written permission until 24 hours have elapsed after the completion of the laying of the blocks in that particular section.

Combined Strip Paving.—Combined strip paving shall consist of creosoted pine paving supplied, prepared and executed in every way of the character and in the manner previously specified, with this exception, that between each two lines of deal paving shall be laid a line of plain Jarrah wood strips, each strip the same depth as the pine paving, and consisting of blocks not greater than 1½ inches thick and 9 inches long, and not less than 1⅜ inches thick and 8 inches long.

These thin Jarrah blocks shall be hand-dipped in a tough mixture of pitch and creosote oil on one side and the bottom only, the two ends being scraped clean, so as to give the smallest possible heading joint. The said mixture of pitch and creosote oil shall be kept hot and extremely fluid in pans continuously heated by oil jets of approved type. After a length of not more than 6 feet run of the paving has been laid, measured along the length of street, a flogging plank shall be put in position and the courses knocked up tight together with a heavy double-handed maul or hammer. The paving shall be finally grouted off and finished in all respects as previously specified for laying wood blocks.

The Surveyor for the Board of Works for the Strand District, London, says (Feb., 1900):

"The system of laying wood pavements during the past twenty years has little altered, and the best pavement is considered to be the soft wood [Baltic timber] creosoted and laid with small joints run in with bitumen and grouted with Portland cement and sand, the whole laid on a Portland-cement concrete substratum. This pavement has given excellent results on steep hills with heavy traffic, where granite setts were found very trying to the horses; the wood, however, has to be kept very clean to give good foothold."

The average cost of maintaining 114,215 square yards in the parishes of St. Margaret and St. John for the year ending March 25, 1899, was 5.2 cents per square yard.

The Surveyor to the Works Committee of Paddington says in a report dated November 4, 1899:

"As the traffic now is so enormous, I am of the opinion that very little advantage is gained by having deal blocks creosoted, certainly not to warrant the entire expense; they are, perhaps, more sanitary the first two years, and prevent a certain amount of soaking into them, but you do not in any way add to the life of the wood, for it is perfectly plain that all descriptions of wood paving after four or five years' wear become wavy and rough; then numerous complaints are made that the roadway is bad and worn out, when such is not the fact, there still being three to four inches in depth of good wood."

In a paper read before the Association of Municipal and County Engineers of Great Britain in the summer of 1899, Mr. Edward Buckham, Borough Engineer of Ipswich, gave a description of the wood pavements laid in that city, which is a good sample of the way such pavements are laid in England at the present time.

The blocks used in the first pavements were of fir, 5 inches deep, and laid on a base of 6 inches of lime concrete. Later, however, the depth of the blocks was reduced to 4½ inches, which is the present standard.

An experimental length of pavement was laid on a 1-inch bed of gravel without any concrete. The advocates of this plan urged that the gravel base would afford a better drainage than the concrete and that consequently the blocks would last much longer.

Experience, however, showed just the reverse, as the moisture, instead of soaking away, worked up through the gravel and the lower portion of the blocks decayed. Consequently concrete was adopted as a base for all wood pavements. In the place of the 6-inch lime base, however, a bed of Portland-cement concrete 3 inches thick was used. The concrete was mixed in the proportion of one part of Portland cement to one part of sand and four parts of gravel. Upon the concrete was spread a half-inch coat of cement mortar, mixed with one part of Portland cement and three parts of sand. Upon this the blocks are laid, with ¼-inch joints, regulated with a lath between them. The laths are afterwards taken out and the joints filled with a grout composed of one part of Portland cement and two parts of sand. This is swept into the joints until they are entirely filled. After the cement of the joints is set, fine gravel and coarse sand are sprinkled over the surface, and the travel allowed to come upon it. The particles of stone are crowded into the surface of the blocks by the action of traffic, and the surface is made much harder in consequence. The early pavements were laid with plain wood, but when they came to be renewed creosoted blocks were used. The life of these pavements has been from eight to ten years for plain wood, while the only street paved with the creosoted blocks for any length of time has been down thirteen years and will probably last fifteen.

It is estimated that creosoting adds 50 per cent to the life of a pavement.

In January, 1903, representatives of the Metropolitan Borough Councils of London met and organized a committee for the purpose of considering the general question of materials and means of paving the streets of London. This committee has continued in existence since that time, and in February, 1912, made its ninth annual report. Despite the previous statement as to its object, which appears in the report, it is also stated that its work is confined to the collation and assimilation of information relative to different materials and methods of paving under varied circumstances, and no attempt is made by it to advocate the use of any particular description of paving. The report goes on further to state that the principal kind of paving laid down during the year under review in main roads was creosoted

soft wood, generally laid close jointed and grouted with pitch, although it as statede lsewhere in the report that in the City of London proper most of the pavement consisted of natural rock asphalt compressed laid to a depth of 2½ inches on 9 inches of Portland cement concrete foundation.

Regarding foundation the report says that while some boroughs favor a foundation of Portland cement concrete 9 inches thick, others appear to consider 6 inches sufficient in main thoroughfares.

The report takes up the work of several boroughs, which is interesting as giving the practice in England, and also the prices for work.

"*Fulham.*—Creosoted deal and creosoted larch 8 in. or 9 in. by 5 in. by 3 in. were also laid, close jointed, grouted in with pitch and cement on existing concrete foundations, at a cost of from 7*s.* 9*d.* to 8*s.* 11½*d.* per yard super. without foundation, but including the making good of existing foundations.

"*Hampstead.*—The wood paving laid in this Borough consisted of 8 in. by 3 in. by 4 in. creosoted deal blocks laid close jointed run in with pitch, and grouted with Portland cement on a 6 in. Portland cement and Thames ballast concrete foundation. The cost of laying per yard super. was 5*s.* 8*d.* and 5*s*, 9*d.* without foundation, and 7*s.* 6*d.* with foundation.

"*Holborn.*—Compressed rock asphalte 2 in. thick was laid, compressed with heated pelons on a 9 in. Portland cement concrete foundation at a cost of from 12*s.* 6*d.* to 13*s.* 9*d.* per yard super., with foundation. A very small area of 1½ in. asphalt was also laid.

"In Shaftesbury Avenue, some 3400 super. yards of creosoted Swedish deal blocks 3 in. by 9 in. by 5 in. were laid pitch grouted with cement finish on a 9 in. Portland cement concrete foundation. These were laid by contractors under a 15 years' maintenance contract which provided for the annual payment by the Borough Council to the Contractors, of 1*s.* 7*d.* per yard super. including first cost of the paving.

"*Kensington.*—The principal streets in this borough were paved with creosoted deal blocks 8 in. by 3 in. by 5 in. and 8 in. by 3 in. by 4½ in. They were laid, grouted with tar, pitch and

cement on a 6-in. Portland cement concrete foundation, by a contractor at a cost of 7*s*. 0–½*d*. to 7*s*. 9*d*, per yard super. without foundation, and 12*s*. 5*d*. per yard super. with foundation. It appears that the paving which this paving replaces lasted in Fulham Road and Kensington High Street 11 years, in Earl's Court Road 17 years, in Bayswater Road 10 years, and in Gloucester Road 16 years.

City of London.—Most of the paving laid in the City during the past year consisted of natural rock asphalt compressed laid to a depth of 2¼ in. on a 9-in. Portland cement concrete foundation. This was put down by a contractor under a maintenance contract at a cost of 15*s*. per yard super. with foundation and 9*s*. without foundation. The annual cost of maintenance per yard super. is 9*d*. The engineer states that the asphalt paving which this paving replaces in Newgate Street and King Edward Street lasted for periods of 17¼ years and 20 years respectively. Two-inch asphalt was also laid in a less busy thoroughfare on an 8-in Portland cement concrete foundation at a cost of 13*s* per yard super. with foundation and 8*s*. 6*d*. without foundation. The annual cost of maintenance per yard super. of this pavement is 5*d*.

"Creosoted deal blocks 3 in. by 8 in. by 5 in. were also put down on an 8 in. Portland cement concrete foundation, the joints being filled in with a boiling mixture of pitch and oil. The work was done by a contractor under a maintenance contract at a cost of from 11*s*. 4*d*. to 13*s*. per yard super. with foundation, and from 7*s*. 8*d*. to 11*s*. without foundation. The annual cost of maintenance per yard super. being from 6½*d*. to 9*d*. Some of this paving replaced hard wood paving which had been previously laid. The engineer states that there are no macadam paved roads in the City.

"*London County Council.*—In Lea Bridge Road, Hackney, where the gradient was 1 in 65 and 1 in 34 creosoted deal blocks 8 in. by 3 in. by 5 in. were put down. These were laid dry and grouted with pitch on a 9-in. Portland cement concrete foundation at a cost of 16*s*. per yard super. with foundation and 10*s*. 3*d*. without foundation. In Belvedere Road, Lambeth, where the gradient is 1 in 61 with a great deal of heavy warehouse

traffic, 9 in. by 3 in. by 5 in. creosoted deal blocks were laid, run with pitch and then cement grout, on a 9-in.-Portland cement foundation, at a cost of 12*s*. per yard super. with foundation and 8*s*. 3*d*. without foundation. In Harrow Road, Paddington, a main road with a gradient of 1 in 700 and 1 in 436, 9 in. by 3 in. by 5 in. creosoted deal was laid, pitch grouted, on a 6-in. Portland cement concrete foundation, at a cost of 12*s*. 5*d*. per yard super. with foundation and 8*s*. 6*d*. without foundation. In Baltic Street and Hatfield Street, Finsbury, 2 in. asphalt was put down on a 9-in. Portland cement concrete foundation, at a cost of 12*s*. 8*d*. per yard super. with foundation and 9*s*. 4*d*. without foundation.

"*St. Marylebone.*—A very large quantity of soft wood paving has been laid in this borough, besides compressed asphalt and tar macadam.

"The creosoted deal blocks, 5 in. by 3 in. by 9 in., were laid close jointed and grouted with pitch and creosote oil on a foundation of concrete from 6 in. to 9 in. deep, varying with the character of the street, the cost of laying being from 9*s*. 0–$\frac{3}{4}$*d*. to 15*s*. 1$\frac{3}{4}$*d*. per yard super. with foundation. The work was done by the Council with direct labor, and the annual cost of maintenance per yard super. is put at 3$\frac{1}{4}$*d* to 8*d*.

"The compressed asphalt was laid to a depth of 2 in. on a 6-in. concrete foundation, the work being done by contract at a cost of 12*s*. 6*d*. per yard super., with foundation.

"*Wandsworth.*—In this borough creosoted soft wood (Archangel thirds), soft wood blocks, 8 in. by 3 in. by 5 in. and 9 in. by 3 in. by 5 in., were laid dipped in a mixture of tar and pitch and grouted with Portland cement mortar on a 6-in. Portland cement concrete foundation. The work was done by a contractor at a cost of 11*s*. 9*d*. per yard super. with foundation. Some of this paving was laid to replace creosoted soft wood paving which had been down eleven years.

"*Woolwich.*—In a main business thoroughfare soft wood 9 in. by 3 in. by 5 in. creosoted blocks were laid grouted in with pitch and tar on a 6-in. Portland cement concrete foundation, at a cost of 12*s*. per yard super. with foundation and 8*s*. 7*d*. without foundation. The foundation was prepared by the local authority, the wood being laid by contractors.

"*City of Westminster.*—Large areas of creosoted pine blocks, 8 in. by 3 in. by 5 in., were laid in the City of Westminster during the period dealt with in this report. The blocks were laid close jointed, grouted with a mixture of boiling pitch and creosote oil, and after with cement grout, top dressed with ⅜-in. ballast on a 6-in. Portland cement concrete foundation. The paving was laid by a contractor at a cost of from 7*s.* 9*d.* to 8*s.* 4*d.* without foundation, and from 11*s.* 2*d.* to 12*s.* 5*d.* with foundation.

"Some 2-in. asphalt was also laid at a cost of about 8*s.* 1½*d.* to 8*s.* 3*d.* per yard super. without foundation, and 13*s.* 6*d.* to 13*s.* 8¾*d.* with foundation."

Wood pavement was first laid in Glasgow in 1841. Beech timber was used, but instead of being sawed into square logs, round timber was cut into short lengths and placed on end. The wood soon decayed, however, and had to be removed. Wood paving was again tried in 1874, when a portion of one street was paved with yellow-pine blocks. The blocks were laid on a foundation of plank and sand, the joints being filled with cement. This pavement lasted only until 1877, when it was repaved by the same company. In 1881 it again required extensive repairs, and in 1885 the entire pavement was removed and a new system of laying blocks adopted. This pavement was laid on a Portland-cement concrete base, and the joints were filled with bitumen. Side streets have since been paved in this manner, and Australian wood has been used to a certain extent, but stone has always remained the principal paving material.

In his report dated October 30, 1897, the Master of Works in Glasgow says: "In regard to the durability of timber as a paving material, the soft varieties, in my opinion, are not at all suited for our city. For the first two years they wear well enough, but after that time give way rapidly. No doubt carbolizing has a favorable effect in preserving to some extent from the effect of moisture. So far as regards the durability of the hard timbers, it cannot yet be stated how age will affect them, but, so far as can be judged from the blocks put down in Buchanan Street, the extent of the wear of the material since laid down seems to be comparatively light, while the substance or fibre of the wood does not show any appearance of being shattered as it does in the soft varieties."

About 1872 wood pavements were laid in Edinburgh with Baltic redwood blocks, but they did not give satisfaction and were taken up after eight or ten years and replaced with stone. The blocks were practically of the same dimensions, and laid in the same manner as those of London.

Dublin, Ireland, also has some wood pavements. The blocks are of beech or pine, 3 inches wide, 5 inches deep, and 9 inches long. These blocks are generally creosoted before laying, 10 lbs. of creosote being used on an average for one cubic foot of wood. The foundation consists of 6 inches of cement concrete, and the joints are partially filled with hot pitch and creosote oil, when the remaining space is filled with a mixture of one part of cement and six parts of gravel, partly to solidify the pavement and partly to protect the pitch and creosote from the action of the sun. This pavement is said to have an average life of ten years.

Wood pavements were also laid about the same time in Berlin, some of American cypress, and others of Swedish pine. It is said that in 1883 a pavement laid in 1879 in Oberwall Street had become so much damaged that half of it had to be relaid, and the other half the following year. In another street a pavement laid in 1879 was replaced by asphalt in 1884.

In 1891 Consul-General Edwards translated from the Berlin *Journal* as follows: " It is reported that the wood pavement which was laid in many parts of Berlin has worn so badly that the Municipal Street Commission has decided to entirely stop using this material for paving purposes. Every sort of wood which has yet been tried has rotted in a comparatively short time, and its upper surface has become so much injured that repairs are hardly possible; also horses fall upon it more easily than upon asphalt pavement."

Paris did not adopt wood as a paving material until after the earlier improvements in London, and not until it had been demonstrated about what the pavement was capable of. It was used, not as a cheap or durable material, but as one that would give results that would be much less noisy than stone and much less slippery than asphalt. The decaying properties of the material were not seriously considered, because it was expected, as proved to be the case, that the pavement would be worn out by the

severe traffic of the streets before any action of decay would set in. The blocks are about $3\frac{1}{8}$ inches wide by $4\frac{3}{4}$ inches high and 6 inches long, and are set directly upon the foundation, the surface of which is made perfectly smooth to receive them. The blocks are set in courses at right angles to the street, with a space of $^7/_{16}$ of an inch between them. Some pavements have been laid with $\frac{1}{8}$- and $\frac{1}{4}$-inch joints, but this is not the custom. The blocks are kept the proper distance apart by strips of wood $1\frac{1}{2}$ to 2 inches broad and about 5 feet long, which are laid obliquely between rows, with the ends projecting above the surface, so that they can be readily withdrawn when half a dozen or more rows have been laid. As soon as they are taken out, hot coal-tar is poured into the joints, so as to fill them to a depth of about 1 inch. The remaining space is filled with a grout made of Portland cement and sand. The surface of the pavement is covered with a thin layer of clean, sharp gravel, so that it may be ground into the surface of the block by traffic, making them harder and more durable. To provide for expansion a joint is left next to the curb about 2 inches wide, which is filled with sand.

Norway spruce and fir were used at first, but later pine from the southern part of France and some pitch-pine from Florida have given better results. Still later experiments have been made with the Australian woods, which will be taken up later on. The average life of the pavements has been from eight to nine years upon heavy-traffic streets. The blocks in some instances have been worn down to half of their original depth. The wear on some ten of the principal streets has varied from .0746 to .2908 of an inch per year. The average cost of wood pavements in Paris has been about $3.47 per square metre, and the cost of maintenance 29 cents per square metre per year. In January, 1897, Paris had 1,339,520 square yards of wood pavements, and 2,400,000 square yards on Jan. 1, 1909.

M. P. Tur, in speaking of the wood pavements of Paris in a paper presented to the First International Road Congress held at Paris in October, 1908, regarding the character of the wood, said:

"Since 1886 the pine of the Landes has come into general use, and to-day the use of this wood has become almost exclusive."

Regarding the depth (or as he called it, the height) he said:

"This height has varied but little during twenty-seven years, due as much to the kind of wood used as to various other considerations. The original height of the blocks was uniformly 15 centimeters. To-day this height is used for the pine blocks of the Landes destined for very much frequented highways, notably the grand boulevards; in fact, on the Montmartre boulevard, blocks of 15 centimeters in height have been worn away uniformly without the road surface losing its regularity.

"For streets of average traffic in Paris a thickness of 12 centimeters is sufficient; it might even be reduced to 10 centimeters. However, blocks of 8 centimeters in height, and especially those of less height, do not give good results as usually laid. Pavements of such slight thickness easily become inclined and displaced."

Regarding the treating of the blocks he says:

"Since the use of wood pavements began efforts have been made to devise some means of protecting them against decay by antiseptic treatment. The City of Paris up to the present has confined itself to soaking the blocks which it manufactures in a hot bath of fat oil, improperly called creosote. This fat oil should contain at least 13 per cent of creosoted products, and at most 8 per cent of napthaline during the winter and 13 per cent during the summer."

Speaking of the thrusts to which wood pavements give rise on account of the swelling he says:

"In practice it is impossible to foresee the circumstances under which any road will absorb water and will expand. The phenomena depends on the quality of the road, the quantity of water with which it was impregnated at the moment of laying and the atmospheric conditions prevalent from that time on. Thrusts are usually exerted perpendicularly to the axis of the road. They usually displace the sidewalk, curbs, and quite often the tracks of the tramways. Sometimes, too, they manifest themselves in a longitudinal direction by more or less extended upliftings of the entire pavement.

The displacement of the curbs and the parts near the flagging never cause any noteworthy trouble, nor do the partial liftings

of the wood pavement. The danger of damage from this cause can be reduced by sprinkling the blocks thoroughly before laying them. In order to facilitate repairing of the sidewalks, a joint filled with sand is made, as we have already said, along the curbs. As for the liftings, which occur more rarely, they are easily removed by extracting one or two rows of blocks."

"*Construction of the Pavement.*—Upon the concrete foundation the blocks are placed so that the grain of the wood is perpendicular to the foundation; they rest directly upon the foundation without any intermediate layer of sand or mortar. Along the sidewalks the pavement is framed by two rows of blocks parallel to the curbstones and separated from them by a joint of 4 centimeters in thickness filled with fine sand. This arrangement does not pretend as its object the forestalling of the effects of the swelling of the wood and preventing the displacement of the curbstones, but it permits the early stopping of this displacement and it facilitates repairing. It is not, however, without its disadvantage, for it offers to the waters of the gutter an inlet by which to reach the under side of the blocks. Unfortunately, as yet no simple and efficacious system has been offered as its substitute; the longitudinal joint has been filled with clay, wood sawdust, tarred oakum and bitumen; the blocks have been dressed in the form of a wedge against the curbstones, but the result obtained has always been indifferent.

"In the same row the blocks are placed in contact with each other so that their joints will break with those of the preceding row. Between two successive rows the width of the joints is at present fixed at 0.8 of a centimeter; to obtain this regularity of width, small reglets or strips of wood are used having a thickness of 0.8 of a centimeter, which are placed edgewise upon the foundation at the base of the preceding row. The laying of the blocks is done with the hacking knife or hand ax; the paver takes from behind him the blocks previously spread out upon the foundation and puts them in place before him, taking care to crowd them up against the strip and bed them well.

"The filling of the joints follows the laying. A mortar of Portland cement containing 600 kilograms of cement to one cubic meter of fine sand is used. The mixture is made dry directly

upon the surface of the pavement; the necessary quantity of water is added and the mass is washed into the joints by means of a broom, a rubber blade, or even a hand trowel. As, however, the first application of the mixture after it has set is not flush with the surface of the pavement, the filling of the joints usually necessitates two successive operations.

"The pavement is next covered, at the time of opening to traffic, with a layer of ordinary sand about 1 centimeter in thickness.

"Finally, several days later, and as soon as possible, during a damp or rainy spell, a layer of porphyritic or granitic gravel is spread to a thickness of from 3 to 4 centimeters upon the road in one or two operations."

In another place, speaking of the thrusts produced by wood pavements on account of the swelling, he says:

"Unfortunately the system which will render wood pavements entirely harmless has yet to be found. The effect of sprinkling of the blocks before laying can never be other than temporary, and it is often ineffective."

During the last years in order to make the pavement correspond to the traffic of the street, blocks even 2 inches thick have been used on residence streets. The blocks, being thinner, permit of their being more thoroughly compressed, so that they make a denser pavement. A pavement of this character cannot have the stability of one 3 inches in thickness, and is only used on light traffic streets.

The wood block pavements of Wellington, New Zealand, are described as follows in the *Engineering Record* of March 8, 1912:

"The roadway is excavated to a depth of $11\frac{3}{4}$ in. below the finished-surface level of pavement. Six inches of concrete (composed of six parts of ballast to one part of Portland cement) are laid over the whole width of the roadway and floated to a smooth surface. Jarrah blocks, 5 in. deep, cut from planks measuring 6×3, 7×3, or 8×3 in., are dipped in hot tar and then laid in courses 3 in. wide across the street, the blocks in each course and the several courses being placed as close together as possible. Expansion joints 1 in. wide of well-worked clay are laid alongside

each curb. The whole surface is coated with boiled tar, well brushed in, and then sprinkled with coarse sand. This tarring and sanding are repeated as found necessary. The sand used is taken from the sea beach, the particles being about the size of rice."

It is stated that these pavements have been in use eight years and have remained in good condition without further treatment than an occasional surfacing of tar and sand.

In 1890 the city of Montreal laid a pavement of tamarack blocks made from 3-inch planks of the following dimensions: 3 inches thick, 5 inches wide, and 6 inches deep. The blocks were creosoted and then laid closely together on concrete, and a coating of hot coal-tar and pitch poured over the entire surface until the blocks and joints would absorb no more, when the entire pavement was covered with fine roofing-gravel about 1 inch in thickness.

Tamarack blocks have also been laid in Quebec, being first used there in 1855. The following description of the pavement is taken from a consular report:

"The street is excavated to a depth of 2 feet, properly graded, and rolled with a horse-roller. Then a foundation is made of wooden flooring of 1½-inch boards laid longitudinally and crossed at right angles by a second flooring of inch boards so as to conform more readily to the crown of the roadway. These are laid with ½- or ¾-inch spaces between so that should any surface-water penetrate it will not remain and freeze, but run through and be absorbed by subsoil, after passing through a layer of sand which is strewn over the flooring to the depth of ½ inch, thus preventing the blocks coming in contact with the flooring. This double flooring is the means of distributing the weight of passing loads over the extent of area, and also prevents any local settlement of the surface. On the flooring are laid blocks of red tamarack about 12 inches long, as sawn from the log, about 10 or 15 inches in size, and placed on end. In the spaces formed around the blocks small pieces of wood are forced, thus filling in and tightening the mass. The interspaces remaining are then filled with a grout made of sand, cement, and tar, or a mixture of finely-sifted coal-ashes and cement. The surface is evenly rolled and covered

with sand, which is allowed to remain until every cavity is filled, when the street is swept clean on the block.

"These roads are very durable. Pavements laid thirty-five years ago were recently taken up and the tamarack blocks had not shown any signs of decay, but had worn down to about half their original length. The surface was as hard as stone, and it is said that there is more resistance to these surfaces practically than stone, because stone, under the influence of water and constant teaming, wears away like a grindstone. The vertical pores of the wooden blocks fill with grit, and the fibres of the wood, like the bristles of a brush, sway to and fro with the traffic of opposite directions without breaking. The blocks are used in their green state, with bark on, which prevents the wood from coming in contact with the filling, and the bark lasts for many years, as precaution is taken to cut down the trees in the proper season after the sap has all been reduced to fibre and before the spring sap begins its ascension through the pores of the wood. The cost of this pavement is from $1.50 to $1.75 per square yard. In the older part of the city a number of the streets are planked with 3-inch pine deals. These streets are very narrow, the entire width being only from 8 to 12 feet."

Just when wood was adopted as a paving material in this country is uncertain. In a report of the Committee on Paving Materials to the Franklin Institute, made in September, 1843, and referred to in the chapter on Stone Pavements, extended mention was made of the wood pavements of Philadelphia. The following quotations from that report will give the standing of wood pavements at that time:

"The hexagonal hemlock pavement laid some years ago in Chestnut Street, between Fourth and Fifth, cost $2.50 per square yard, and was decayed to such an extent as to require renewal within three years."

"The squared-block wooden pavement in Third Street, of Northern spruce, cost about $2.25 per square yard, and after three and one-half years' use the hemlock portion of it is very much decayed and needs renewal, while the heart yellow-pine portion is still in apparently good order, although presenting strong symptoms of decay. This pavement was laid in September, 1839, and

the hemlock will probably require removal in the course of the present year [1843]."

"The wooden pavement of white cedar formed of oblique prisms, dowelled together on the Count de Lisle's plan, which was laid in Walnut Street in 1840, cost $1.75 per square yard and is still in good order."

"The cubical hemlock pavement in front of the State House, laid in July, 1839, has so extensively decayed that it has this year been replaced by a cubical pavement of stone laid upon the diagonal plan."

"The squared hemlock-block pavement laid in Spruce Street cost about $2 per square yard in November, 1839, and although exposed to very little travel, it now exhibits unequivocal symptoms of speedy destruction. The hemlock which has been chiefly used in Philadelphia for wooden paving is certainly the most unsuitable timber that could have been employed for such purpose. Nevertheless its very rapid decay showed but too clearly the great liability of wood in general to rot under such circumstances."

The Committee instanced one example of a wooden pavement laid with chemically-treated blocks, which they stated were much decayed at that time, but did not give the date of laying. They add, however, that it was stated that the blocks were somewhat rotten prior to being boiled in the solution of the sulphates of copper and iron. They conclude their deductions as follows:

"Finally, in consequence of the slippery nature of their surface, their deficiency of durability when of ordinary timber, of their expense in the ultimate, and in view of results of experience as far as they have become known to us, we are reluctantly impelled to the conclusion that, though their use may be proper in some detached situations, wooden pavements ought not at this time to be recommended as part of the general system of paving by the city of Philadelphia."

They also added that since the report was written they had learned that the authorities of New York had determined to take up their decayed wooden pavements and relay them with stone; also that they had learned with regret that the experience of Boston had been practically the same as that of Philadelphia and New York.

While only history, the above is interesting and important, as it shows the conclusion arrived at at that time to be practically the same, as relates to this particular material, as would be found by a committee of engineers appointed for the same purpose at the present time; and if this conclusion had been accepted by the cities of the country as a whole, a large amount of money would have been saved that has been wasted in experimenting with wood pavements.

Probably no city in the country has had as great a variety of pavements laid with this material as the city of Washington. When the Board of Public Works of that city was appointed in 1871, the pavement question was far from settled, and a great many experimenters were in the field. Previous to this date there had been a little over 100,000 square yards of wood pavement laid in Washington and Georgetown. Just what kind this was is not known, but probably quite a proportion of it was the Nicholson, as that was laid in many cities previous to 1870.

Subsequent to 1871, and under the authority of the Board of Public Works of the first Board of Commissioners, there were laid in Washington 1,087,738 square yards of wood pavements, under twelve separate patents. These had cost from \$2 to \$4.20 per square yard. They soon began to decay, and after two or three years began to be replaced, and between 1875 and 1878 over 315,000 square yards had been removed. From this time on they were gradually replaced by other material, until in 1887 about 18,403 yards were left, and the last was removed in 1889. In a report to the Engineering Department in 1887, the Commissioner says, when speaking on this subject: "Cedar-block pavements used so extensively throughout the Northwest are cheap—\$1 to \$1.30 per square yard—but deteriorate rapidly, are objectionable on sanitary grounds, and are anything but smooth for street wear. Creosoted wooden blocks, with a hydraulic-cement foundation, when closely laid, approach nearest to the ideal block pavement. Those in the form of the blocks of the Ker Pavement Co., New York, are a fair example of this class. These are laid with creosoted wooden blocks, $6 \times 9 \times 3$ inches in dimension. The wood fibre is placed vertically to a depth of 6 inches; ⅜-inch joints are left which are filled, 1 inch with hot asphalt and 3 inches with

Portland-cement grouting. The resulting pavement is clean, noiseless, smooth, and not slippery."

Very little information can be obtained concerning the early wood pavements of New York and Boston, but they were in use in both cities previous to 1839, and the statements of the Committee of the Franklin Institute no doubt expressed the conditions fairly.

St. Louis also had some experience with pine and cottonwood pavements, some laid plain and others treated chemically, but with the same results as the other cities mentioned.

Between 1860 and 1870 a large amount of wooden pavement was laid in many cities in this country under the Nicholson patent. The best description of this pavement can probably be obtained by quoting from the Brooklyn specifications in a contract made in 1869:

"The wooden blocks of the Nicholson pavement are to be of sound white pine or Southern yellow pine, sawed so as to be 3 inches thick and 6 inches long; the blocks for paving the kennel to be sawed to a uniform level so that a channel-way for surface-water will be formed outside the curb-lines. The flooring for blocks, and the pickets to be used between each traverse course of blocks, to be of sound common pine boards, conforming to 1 inch thickness, the whole 2 inches wide and 1 inch thick. The foundation or sand bed which is prepared is to be brought to a proper crown and width to the street edge and then covered with sound common pine boards of the dimension described, paved lengthwise to the line of the street, the ends resting on similar boards laid transversely from curb to curb; the flooring to be well and thoroughly tarred on both sides with hot coal-tar brought to the proper consistency with paving-cement, so as to be tough and fibrous and not brittle when cool. Upon this floor of plank the blocks are to be set on end in parallel courses, transversely with the line of the street; each block before laying to be dipped to half its height in hot coal-tar and paving-cement prepared as described; each course to be separated by a course of pickets placed on the face of the blocks and to be properly nailed; the space between each course of blocks about the pickets to be filled with clean roofing-gravel and hot coal-tar, and then the cement thor-

oughly mixed and compactly rammed by means of a paver's rammer and an iron blade made to fit the interstices or spaces between the blocks; the gravel to be very thoroughly dry and warm, so as not to chill the tar; the coal-tar in all cases is to be boiled down and so thickened with paving-cement as to be tough and fibrous when cool and not brittle even in cool weather, and is to be applied hot and in such quantity as will thoroughly penetrate and fill all the joints; the whole surface of the pavement, as rapidly as the grouting shall be completed, is to be covered with hot tar and paving-cement as above specified, and then covered with fine sand and gravel and not less than $\frac{3}{4}$ of an inch thick."

This pavement in Brooklyn cost $4.50 per square yard, with an additional sum of 50 cents for grading the street and preparing the foundation. The blocks for this pavement could be either treated chemically or not, according to the belief of the special set of authorities in control. This pavement when first laid was very smooth and presented a pleasing appearance to the eye, and for the time was extremely popular, but it soon began to decay, and unless frequently repaired was rough and uneven, and as the decay continued became unhealthy and unsanitary. Its average life in Brooklyn was about six years, and in St. Louis five years and six months.

Memphis, Tenn., laid a large quantity of this pavement, which, however, soon decayed, requiring relaying, when entirely different material was used.

Another pavement very similar to the Nicholson, and laid about the same time, was what is known as the Alexander Miller & Co.'s Improved Wood Pavement. The principal difference between this and the Nicholson was in the shape of the blocks, which were sawed on a bevel so as to be 4 inches thick at the base, 3 inches thick at the top, and 6 inches deep, so that when set together at the bottom they left an open joint 1 inch wide at the top. In Brooklyn these blocks were laid on Burnettized spruce planks $1\frac{1}{2}$ inches thick. These planks were laid lengthwise to the street, resting on similar planks laid transversely from curb to curb. The spaces between the blocks were filled with coal-tar and pitch, and the surface of the pavement covered in the same way as that prescribed for the Nicholson pavement. This pavement cost

in Brooklyn $4.90 per square yard, and its life was practically the same as that of the Nicholson.

After the failure of these pavements, and when many of the Western States which were far from supplies of stone had attained such size and importance that street pavements became a necessity, wood was laid in an entirely new way. Chicago and Detroit, wishing a new and cheap pavement, and being so situated that they were in close connection with the cedar-swamps of the North by means of water communication, finally took up in earnest what is the well-known cedar-block pavement of the West.

These blocks were made of cedar posts, from which all the bark had first been removed, sawed into pieces 6 inches long, by gang-saws cutting from six to eight blocks at once. These blocks varied in diameter according to the dimensions of the posts, but the specifications generally called for them to be from 4 to 8 inches in diameter, or, if larger, the blocks were to be split before being laid in the pavement. The blocks were laid on different foundations, some simply on beds of sand, some upon a base of sand and gravel, some on sand and broken stone, some on sand and hemlock boards, and others on a concrete base with a sand cushion. The great and almost only merit of these pavements was their cheapness. They were quickly laid and, when new, made a pleasing and apparently satisfactory roadway.

There was considerable discussion as to the best foundation. A sand base could not give satisfaction, as it was easily displaced and the surface became rough and uneven before the blocks began to decay. The blocks laid on hemlock planks maintained their surface as long as the blocks and the planks remained sound, but when either or both began to decay, they soon became rough and in a short time almost impassable.

The advocates of this foundation held that the block pavement was cheap and only temporary at best, that the hemlock foundation would last as long as the blocks, and that when the pavement was renewed it might as well be replaced complete. The advocates of the broken-stone and concrete bases, however, maintained that if a permanent base were laid at the same time as the pavement, when the blocks did decay and required replacing, a good foundation would be in position for whatever material should be selected,

whether brick, stone, or asphalt. The opponents of this theory argued that a concrete foundation held the moisture which would drain off through the stone or sand, and would cause the blocks to decay more rapidly than otherwise. This, however, was not borne out by experience, as the life of the pavements, whether laid on sand or on concrete, did not vary materially.

The blocks were laid on a prepared foundation very simply, the only object being to get them laid closely so as to form as small a space as possible between each individual piece. The blocks were rammed and the space filled with clean, coarse gravel previously heated and dried, and then poured full of paving-cement, the specifications generally requiring two gallons per square yard. Between 1880 and 1890 many millions of yards of this pavement were laid in the cities of Chicago, Detroit, St. Paul, Minneapolis, Omaha, and Kansas City, and many other smaller cities throughout the Central West. The pavement being cheap and all these cities at that time having an unprecedented growth, a much greater amount was laid than would have been under ordinary circumstances, as the real-estate boomer desired to have a paved street in front of his property long enough to sell it, no matter what might be its eventual life. This pavement lasted ordinarily about five years in good condition, when the decay was generally so great as to make it rough and undesirable for travel, and in a few years more it became practically impassable and required renewal when it had been down seven years.

In 1888, in Omaha, Des Moines, and Kansas City there were laid pavements practically the same as those just described, except that the material was cypress from the swamps of Arkansas. This wood was much heavier than cedar, more dense and compact, and from appearance would be more durable, but there is probably no material produced by nature about which as little can be ascertained by a preliminary examination as wood. The only sure way to find out its durability is by experience. In an actual test of abrasion, cypress would probably have outlasted cedar, but as far as decay from the atmosphere was concerned it was much shorter-lived, and the cypress blocks had not been laid more than two years before they began to show serious signs of decay. This in itself proved beneficial, as it prevented a larger amount from being

laid. While heart cypress has deservedly a good reputation for durability, the sapling wood in all of these instances plainly showed itself of no value.

One street in Omaha which was paved with cypress blocks in 1888 was repaved with brick in 1892, and the other streets paved with the same material had about the same life.

When the Tenth Street viaduct in Omaha was completed in 1889, it was decided to pave the roadway with cypress blocks; but in this instance the inspector went to the Louisiana swamps to see the timber cut and sawed, selecting only the best trees, so that the best results could be obtained. Despite this precaution the pavement lasted but nine years.

It is a well-established fact that wood, if kept continually wet or continually dry, will last for almost an indefinite period, but when so situated that it becomes alternately thoroughly wet and then thoroughly dry it will rapidly decay. It has been argued by many, reasoning from this knowledge, that the reason why the cedar-block pavement in the West decayed so much more rapidly than some which had been laid further East was because during the summer season quite a time elapsed without rain, and the blocks became so thoroughly dry that when rain did fall the pores were entirely open and rapidly absorbed the moisture, which, when the pavement became dry again, was quickly evaporated, and the process being repeated, the wood was placed under its worst conditions for durability. While there is no doubt that there may be some force to this argument, it is undoubtedly true that cedar blocks will never become a recognized paving material.

In order to prevent this decay and make the pavement as durable as possible, blocks were used in Michigan from which all the sap-wood had been removed and were accordingly called "sapless cedar blocks." These blocks were hexagonal in form and could consequently be laid with tight joints; but while their durability was greater than the ordinary blocks, the cost of making was so great that the advantage was not enough to warrant their general use.

The city of Chicago, growing as rapidly as it has, and situated at the foot of Lake Michigan, where wood of all kinds is cheap,

and where a great amount of street pavement must be laid every year, now uses a large amount of cedar blocks. It was seriously argued, and with some force, that, on account of its small first cost, it was cheaper to use cedar blocks, even if they did require relaying every five or six years, than to lay a more permanent and more expensive pavement. While this might possibly be true as far as economy is concerned, the result has been that Chicago has had many miles of badly paved and extremely dirty streets, as during the last half of the life of the cedar pavement it is very rough and almost impossible to keep clean except at great expense. On January 1, 1897, Chicago had 752.68 miles of cedar-block pavement, and during the year 1897 there were laid 23.53 miles. On January 1, 1900, the mileage was 763.21. In 1897 the average cost of this pavement laid on a plank base was 70 cents per square yard, and when laid on 6 inches of broken stone, 85 cents per square yard. The City Engineer at that time said: "The plank foundation is considered to be the best, as the wearing surface is more even, and the planks last as long as the blocks, and whenever the pavement is renewed the street is torn up, as, for instance, by the gas company renewing the calking of their pipes, and the city laying new conduits. In such cases it is necessary to relay the macadam." On January 1, 1911, the cedar block pavement in Chicago had been reduced to 273.59 miles.

Chicago Specifications.

"Upon the subgrade as above prepared shall be spread a layer of clean sand not less than two inches in depth over the entire surface of the roadway.

"In this layer of sand shall be imbedded 1 × 8-inch sound pine stringers, extending from curb to curb and conforming to the grades furnished by the Engineer. The sand between the stringers shall be thoroughly compacted by ramming and then struck off with an approved template which will leave the top of the sand parallel with and one-quarter inch above the tops of the stringers. The stringers shall be spaced so as to support the floor-planks at the ends and centres thereof.

"On the stringers and sand bed constructed as above, two-inch sound hemlock planks shall be laid lengthwise with the street and close together. Each plank must be firmly bedded throughout, and the cracks between the planks are to be filled sand. The flooring when finished must have a true and uniform surface.

"Upon the plank foundation shall be set cedar blocks resting squarely on their ends and well driven together. The interstices between the blocks to be not less than three quarters of an inch nor more than one and one-half inches in size. No square holes will be allowed.

"The blocks shall be of live cedar free from bark, perfectly sound, and not less than four inches nor more than eight inches in diameter, and shall be six inches in length. Blocks more than eight inches in diameter must be split, but split blocks less than three inches thick cannot be used. All corners must be cut off from the split blocks so as to make close joints, and no two split sides shall come together.

"The surface of the pavement must be true and uniform.

"The blocks shall be carefully inspected after they are brought on the line of the work, and all blocks or other material which in quality or dimensions do not strictly conform to these specifications, or which may be otherwise defective, shall be rejected and must be immediately removed from the line of the work by the contractor or contractors. The contractor or contractors shall be required to furnish such labor as may be necessary to aid the inspector in the examination and culling of the blocks and other material, and in case the contractor or contractors shall neglect or refuse to do so, such labor as in the opinion of the Board of Local Improvements may be necessary will be employed, and the expense incurred shall be deducted from any money then due or which may thereafter become due the contractor or contractors.

"The spaces between the blocks shall be filled with clean, screened, dry gravel of one-half to one and one-half inches in size, the proportion of said gravel to be such as to completely fill the interstices. The gravel shall be thoroughly rammed with proper tools and by competent and experienced help, and the interstices

again filled with the same kind of gravel and again thoroughly rammed.

"In the above ramming each interstice must be struck three full blows and driven down well. Two competent rammers must be constantly employed after each paver. No teams will be allowed on the pavement before it is properly rammed.

"After ramming the blocks are to be covered with a paving-pitch which is the direct result of the distillation of 'straight-run' coal-tar, and of such quality and consistency as shall be approved by the Board of Local Improvements. The pitch must be used at a temperature of not less than 280° Fahrenheit and be spread in such quantity as to apply two gallons to each square yard of pavement. The spreading must be done in sections if the Engineer so directs. The contractor or contractors shall provide the Engineer, or his representative, with a duplicate delivery-ticket for each and every load or tank of paving-pitch delivered on the work. The ticket must be signed by the consignor of the pitch, and be of a form approved by the Board of Local Improvements.

"Immediately after the spreading of the paving-pitch, and while it is still hot, the same shall be covered to a depth of not less than three-quarters inch with dry roofing-gravel, or gravel screened from that used to fill the spaces between the blocks. This gravel must be entirely free from sand or loam, and not to exceed one-half inch in size.

"All gravel must be clean, washed, dried, and heated enough to prevent the chilling of the pitch.

"The tarring and top dressing must be completed each day to within twenty-five feet of the face of the blocking.

"If the blocks that have been laid, gravelled and rammed should become wet before being tarred or top-dressed, they must be taken up and reset, without compensation therefor, should the Engineer so direct.

"At the ends of the wings, etc., the pavement must be protected by wooden headers consisting of three-inch planks firmly secured by split cedar posts four feet long, spaced not more than four feet apart."

In the Southern cities wood pavements have been laid of different material. San Antonio, Texas, has used blocks made of mesquite, hexagonal in form, which have given good results, and other cities have tried blocks made of Osage orange-wood. Galveston, Texas, is a city that has also been quoted very frequently as having good wood pavements. In response to an inquiry on this subject in December, 1899, the City Engineer says:

"We have some creosoted pine blocks from 6 to 10×4×6 inches. About 75,000 square yards were laid in 1874, which, even now, except where the pavement has been disturbed for street-car tracks, gas- and water-pipes, is in good condition. The blocks were laid at right angles to the sidewalk curbs on a sand foundation, with an inch space between, which space was filled in with a wedge driven down about 2 inches below the top surface of the blocks and penetrating about 2 inches into the foundation below the bottom of the block, the space above the wedge being filled with tar and gravel, and in 1892, 3, 4, and 5 there were laid some four or five miles of creosoted pine-block pavement. In this instance the blocks were laid touching without any wedges, and tar was spread over the top, and sand over the tar. This last pavement has given endless trouble by swelling and buckling, and kicking out the sidewalk curbs after every rain, especially when the rain followed a dry spell. I relaid a couple of blocks (about 3500 square yards) with wedges and tar and gravel with some of the displaced blocks about a year ago, but it is beginning now to show distress. We have some cypress blocks, laid with wedges some ten or fifteen years ago, that did good service for eight or ten years, but they are now rotten and in a very unsanitary condition. If enough oil is put in pine blocks to prevent swelling, I am satisfied they would make excellent paving material. They have a wonderful ability to resist abrasion."

Oakland, Cal., has laid some pavement of redwood blocks which was described somewhat in detail in the chapter on Pavements. In arguing in favor of this pavement in his report for the two years ending June 30, 1898, the Superintendent of Streets says that in East Twelfth Street in San Francisco, where 2½ inches of the best quality of bitumen rock pavement was completely worn out twice in one year, the property owners petitioned

that the street be repaved with redwood blocks. At that time he said the pavement had been down three years, without any expense whatever for maintenance; that it was then in comparatively good condition, although showing some signs of wear, so that a few individual blocks must be removed at once. He adds that it was the success of this particular piece of wood pavement that induced the property owners of Oakland to select redwood blocks for East Twelfth Street.

Indianapolis, Ind., is the first city in the United States to lay treated wood as an improved pavement.

Mr. M. A. Downing, President of the Board of Public Works, in a paper read before the American Society of Municipal Improvements at Toronto, in 1899, describes Indianapolis wood pavements in detail. He claims that the almost universal failure of wood in street pavements in this country has been generally the fault of the engineers not selecting suitable wood, or not taking proper precaution to prevent it from decay. After studying all the wood pavements in this country and in Europe, the Indianapolis authorities laid red-cedar rectangular blocks from the State of Washington, without any treatment. They were laid with close joints on a concrete base and 1-inch sand cushion. These pavements have now been down five years and are considerably worn and some have decayed. In 1896 four streets were paved with the same material, except that the blocks were creosoted. The dimensions of the blocks were 4 inches wide and 5 inches deep, and laid at an angle of 45° with the curb. The joints were laid close, and no provision was made for expansion at the curb. Some little trouble has been experienced on account of the blocks bulging, and mainly on streets paved with the plain blocks, but some trouble has occurred with the creosoted blocks. On account of this, the Board of Public Works adopted heart-wood of the long-leaf Southern yellow pine, with the block 4 inches wide, 4 inches deep, and creosoted. These blocks were laid as above described, except that a space of from 1 to 2 inches was left next to the curb for expansion. This space was filled with sand and covered with hot paving-pitch. The interstices between the blocks were partially filled with fine, dry sand, when the entire surface was rolled

smooth and then covered with hot paving-pitch and fine gravel screenings. These pavements gave no trouble on account of expansion, and although they have been laid three years, no wear is noticeable. The Board of Public Works feel that the creosoted pavement has been a success in every way. Its cost has been from $2.10 to $2.50 per square yard.

The following are the specifications for this work:

"1. The wearing surface will be composed of creosoted wooden blocks, of either of the following varieties as may be designated by the Board of Public Works at the time of letting the contract: Long-leafed yellow Southern pine blocks, short-leafed yellow Southern pine blocks, or hemlock blocks. Bidders in submitting bids shall submit sample of each of the above-named varieties, and shall state a price on each kind separately. All blocks shall be of sound timber, free from bark, sap-wood, loose or rotten knots, or other defects which will be detrimental to the life of the blocks or will interfere with the laying of the same. No second-growth timber will be accepted.

"2. Blocks shall be subject to inspection whenever required by the City Engineer, and shall be in all respects satisfactory to him. The contractor shall furnish all labor to handle and cull blocks. All condemned blocks must be removed from the street at once.

"3. After the blocks have been inspected and found satisfactory, they shall be placed in an air-tight chamber, where, by means of superheated steam and the use of a vacuum-pump, all sap in the blocks shall be vaporized and then removed. When the blocks are thoroughly dry, and while the cylinder is under a vacuum of fifteen or twenty inches, heavy creosote oil, weighing 8.8 lbs. to the gallon, shall be admitted into the cylinder and pressure added until the pressure in the cylinder shall be at least fifty pounds per square inch. The blocks shall remain in the cylinder until they have absorbed ten pounds of oil per cubic foot of timber and until the creosote has impregnated the timber uniformly through the entire thickness of the blocks.

"4. The blocks shall be four inches in depth and four inches thick, the length being about nine inches; the fibre of the wood running in the direction of the depth. They shall be laid with

the length at an angle of 45° to the curb, in courses extending across the street. The blocks in adjoining courses shall break joints. The courses shall be laid strictly parallel and the blocks shall be driven close together. Where curb is used other than a form of combined curb and gutter, three courses shall be laid next to and parallel with the curb.

"5. The joints shall be filled with paving-cement which shall be as nearly as possible to the condition of being pliable, not brittle in cold weather, and so solid in hot weather that there will be no tendency to run out of the joints. It shall be equal or superior in quality to a cement composed of 10 per cent of refined Trinidad asphalt mixed with 90 per cent of coal-tar paving-cement, distilled at a temperature of not less than 600° Fahrenheit. The temperature shown on the gauge attached to the cement-tank shall show not less than 300° Fahrenheit while the cement is being applied, and shall show such higher degrees as the Engineer may direct, if considered necessary by him on account of weather or character of materials used, to render the cement fluid enough to run into the joints properly. The paving-cement shall not be used unless the blocks are thoroughly dry. Any excess of cement on the surface shall be broomed off so as to leave as little as possible thereon. Great care must be taken not to disfigure the curb, walks, or lawns with material, and any damage on this account must be repaired by the contractor. Extra care must be taken and extra material must be used at the gutters and around catch-basins or other structures, in filling all joints in both paving and curbing, to effectually prevent the leakage of water into the sub-roadway. All joints shall be completely filled to the top before the top dressing is put on.

"6. The surface of the pavement when completed as above shall be covered with a one-half-inch top dressing of clean, coarse sand or granite screenings. All excessive sand or granite screenings not to be taken up by the blocks shall be removed by the contractor, without additional compensation, as soon as directed by the Board of Public Works or the City Engineer.

"*Note.*—The wooden blocks are laid on a 6-inch hydraulic-cement concrete foundation on which is placed a 1-inch cushion-coat of sand."

Wood Pavements in Australia.

During the last twenty years, Sydney, New South Wales, has laid a large amount of pavement with the hard woods of that country. The blocks are 3 inches wide, 6 inches deep, and 9 inches long. They are laid generally on a base of 6 inches of cement concrete over which is spread a thin layer of cement mortar mixed in the proportion of one of cement and two of sand, so as to give a perfectly smooth surface to the concrete. The blocks, after having been dipped in tar heated to the boiling-point, are laid at right angles to the curb, with a 2-inch expansion-joint at the curb which is filled with puddled clay. All the first pavements were laid with an inch space between the courses, the joints being filled with gravel and paving-pitch; but experience soon demonstrated that the open joint was a mistake, as the edges of the blocks broomed and wore down under traffic, so that the surface soon became rough and uneven. After some of the pavement had been laid ten or eleven years, the blocks, having shown no signs of decay, were taken up and the ends sawed off and relaid with close joints.

Many different kinds of wood have been used, and under ordinary traffic the early pavements wore as follows: Blue gum, $^1/_{10}$ of an inch per annum; mahogany, $^1/_8$ of an inch; turpentine, $^1/_{17}$ of an inch; beech-box, $^1/_7$ of an inch; spotted gum, $^1/_7$ of an inch; baltic, $^1/_{10}$ of an inch; colonial cedar, $^1/_{12}$ of an inch; black butt, $^1/_{22}$ of an inch; red gum, $^1/_{10}$ of an inch.

After seventeen years' experience, the City Surveyor of Sydney decided that tallow-wood, black butt, blue gum, red gum, and mahogany were the best, the wear under the improved methods of laying being from $^1/_{80}$ to $^1/_{60}$ inch per annum.

In a paper read before the Institution of Civil Engineering in 1894, Mr. Walter A. Smith gave some interesting details as to several wood-paved streets in Sydney. Martin Place, 64 feet wide between curbs, was paved with close joints. The blocks were of the usual size and laid on a concrete base 9 inches thick, on which was spread a ½-inch coat of cement mortar, mixed one part of cement to three parts of sand.

On the surface thus prepared the blocks were laid, having been

dipped twice in hot tar and allowed to stand two days for the surplus tar to drain off. The blocks were of tallow-wood and red mahogany. Hot tar was then spread on the surface and broomed into the joints, over which was spread a thin coating of sand and, before traffic was allowed on the street, an additional coating of stone screenings. An expansion-joint one and one-half inches wide was left next to the curb, and filled with mastic. The roadway, although 64 feet wide, had a crown of 3 inches only.

Mr. Smith states that in joining the new with the old pavement, that had been laid some six years, with a cement joint, the width of the joint being marked by iron studs projecting $\frac{3}{8}$ of an inch, it was found that dry-rot had set in wherever the wood had been in contact with the cement. Although different kinds of timber had been used, every block was found to be more or less affected. This decayed timber was examined microscopically, but no signs of fungoid growth could be discovered. It was therefore decided that the dry-rot was caused by chemical action between the cement and the wood. In another place where is was necessary to take up blocks that had been laid eight years, where the joints had been filled with tar, pitch, and stone screenings, the timber was found to be in a perfect state of preservation, and although the pavement had sustained a daily traffic of approximately 25,000 tons for eight years, it was practically as good as when laid, the greatest wear observable on the blocks being $^1/_{16}$ of an inch.

Mr. Smith states that in Sydney there are blocks which have been laid thirteen years, on one of the busiest streets of the city, which had only worn $^9/_{16}$ of an inch, and, from their condition when examined, seemed to be good for ten years' more service. He estimates the life of the hard-wood pavement in Sydney at not less than twenty-one years. These pavements cost $2.43 per yard for close-jointed work, and $2.66 per yard with $\frac{1}{4}$ or $\frac{3}{8}$ asphalt joints, exclusive of the concrete foundation.

In 1895 Twentieth Street, New York City, between Fifth Avenue and Broadway, was laid with Australian harri-karri wood. This pavement was laid as an experiment, at the expense of the promoters, in practically the same manner as that just described, with an expansion-joint next to the curb. This pavement has now

been in constant use for nearly five years, and, except where openings have been made, is practically as good as when laid. When the work was being completed, the supply of Australian wood was exhausted, and the Fifth Avenue end had to be completed with cedar blocks. This portion of the work is considerably worn, showing very clearly the superiority of the Australian wood. The surface is as smooth as asphalt, and has given some trouble on account of itsslipperiness, it having at times required sanding. This pavement was relaid in 1905 with creosoted long-leaf yellow pine blocks.

Chemical Treatment for Timber.

Mention has been made of wood paving-blocks that have been treated chemically. Whether this is of practical benefit or not engineers are not wholly agreed. A careful study of the question, however, would seem to indicate that it must be decided by existing conditions in each case. If a pavement is to be subjected to so heavy a traffic that the blocks will be worn out before the action of decay sets in, it would seem unnecessary to treat them chemically unless such treatment would enhance their wearing qualities, an effect which has not as yet been demonstrated. On the other hand, where traffic is light, and the life of the pavement governed by the action of the elements rather than by traffic, any treatment that will increase its durability is worthy of consideration. Then, too, some woods are more susceptible to treatment than others, while some should be treated green and others not until they are seasoned, dependent often upon the character of the chemical used.

There is not sufficient space, nor is there the disposition in this work, to detail at any length the different preservatives that have been applied to timber. It is desirable, however, to give a brief outline of the industry, showing something that has been done, and what are the most approved methods of preserving timber at the present time.

A commission appointed to investigate wood pavements and the preservation of wood for paving purposes reported to the Mayor of Boston in 1873. From their report and the one made by the

Committee of the Franklin Institute in 1843 many of the historical facts herein contained are taken.

In 1657 Glauber recommended treating wood with tar as a preservative. In 1791 a patent was issued to a Mr. Murdock for preserving timber from decay by painting it with a mixture of sulphide, arsenic, and zinc. From that time on a great many methods have been proposed, but those at present in use consist of injecting different kinds of antiseptics into the pores of the wood. The methods best known are those called "kyanizing," "burnettizing," and "creosoting." Kyanizing takes its name from a Mr. Kyan and consists of an application of corrosive sublimate which is injected into the pores of the wood. Mr. Burnett used a solution of chloride of zinc; while creosoting consists of injecting creosote oil. The last two are the methods that are generally used at present both in this country and in England. Burnettizing was first introduced in England in 1838.

Sulphide of copper has also been used very successfully in Europe, but it is said that it cannot be used under all circumstances—that it protects fully only green wood that contains much sap. Railway ties laid on the Northern Railway of France in 1846 treated with this material were found in as good condition as ever in 1885, while those untreated had been replaced some time before by new ones.

An article in the *Engineering News* for 1895 describes the treatment adopted by the Southern Railway for preserving their ties. The timber is placed in a strong, tight cylinder in which a vacuum is created and live steam turned on until the temperature is raised to 125°. A vacuum-pump is then attached to open the pores of the wood. The live steam is admitted the second time under a pressure of 30 pounds per square inch for six or eight hours, the temperature not exceeding 250° Fahrenheit. The steam is again blown off and a third vacuum created, 24 to 36 inches, and maintained from four to six hours at a temperature of 225°. The cylinder is then filled with creosote oil; the pumps are started and the pressure raised to about 100 pounds per square inch and maintained for over two hours, when the cylinders are opened and the oil drawn off and the timber taken out. The average time of treat-

ment for each charge is from eighteen to twenty hours, and the amount of oil used $1\frac{1}{4}$ gallons per cubic foot of timber.

In burnettizing the process is similar to the above, except that a zinc solution is used instead of creosote, and the steam is held at 30 pounds for three and one-half to six hours instead of from six to eight hours. The average time of this treatment is from eleven to twelve hours, and the amount of absorption $4\frac{1}{2}$ gallons per cubic foot. The solution contains 1.7 per cent of pure zinc chloride, a mixture consisting of 34.46 pounds stock solution (43 per cent chloride, 2 per cent impurities, and 55 per cent water) to 100 gallons of water. The officials of the road say that burnettizing makes the timber hard and brittle, and for that reason it should not be used where it is subjected to any strain. Consequently their practice is to use chloride of zinc for preserving ties, and creosote for bridge-timber, etc.

Mr. Walter W. Curtis read a paper before the American Society of Civil Engineers on the 17th of May, 1899, on the preservation of railway ties by zinc chlorides. He states that the first road to adopt the treated ties, other than as an experiment, was the Atchison, Topeka, and Santa Fé Railway. This road built a plant for treating timber chemically in Las Vegas, New Mexico, in 1885. At first the Wellhous, or zinc-tannin, process was used. This process differed from burnettizing in that the solution of zinc chloride contained a small amount of glue, and after the first injection was followed by another composed of a solution of tannin, the effect being, it was claimed, that the tannin formed with the glue small particles of artificial leather, insoluble in water, which would fill the ducts of the wood and retain the zinc chloride.

Latterly the burnettizing method has been used, the full number of ties treated in thirteen years being about three million. The officials of the road are satisfied as to the value of the treatment, but are uncertain as to the relative values of zinc tannin and the plain zinc-chloride methods, the former costing several cents more per tie than the latter.

A plant built in Chicago in 1886 treated a larger number of ties. The Chicago, Rock Island, and Pacific Railway used the Wellhous process until 1896, when it was modified by omitting the glue in the zinc chloride and injecting it in a solution by itself

followed by a third injection of tannin. This change was made because it was thought that the mixture of the glue with the chloride solution decreased its fluidity and made very difficult the injection of the necessary amount of chlorine.

The early practice was to treat all ties without regard to condition as to soundness or dryness, but latterly no unsound or saturated ties have been used.

In 1890 the Chicago Tie Preserving Co. treated some experimental ties for the Duluth and Iron Range Railway. They consisted of 85 ties of white pine, 85 of tamarack, and 86 of Norway pine. They were cut during the winter of 1889 and 90, treated in October, and placed in the track almost immediately with ten each of the same kind untreated, which were cut at the same time. In 1898 it was found that the treated ties were not only free from decay, but were more dense and had cut less under the rail. It was deemed that the ties would last fifteen years longer, while the untreated ties were completely worn out. The average of the untreated ties on this road was from seven to eight years.

Mr. Curtis says that to treat dead or dozy wood is a waste of time and chemicals; that the chloride of zinc has apparently no power to stop decay which has already begun, and it is doubtful if any other treatment is better in that respect. In speaking of foreign practice, he says that France and Great Britain use the creosote process almost entirely, burnettizing not having been satisfactory.

The German railroads have used either zinc chloride or a combination of chloride and creosote, and sometimes creosote alone. Since 1895, Prussia state railways have used a zinc-creosote process, consisting of injecting equal amounts of zinc chloride and creosote to the amount of 1¼ lbs. per cubic foot of timber. He says that one road was furnished with 171,000 pine ties treated with the zinc-creosote process under nine years' guarantee. At the end of the nine years only 29 had become unfit for use, and none of these was rotten. The cost of treating these with chloride of zinc for the German railways in 1896 was 13 cents for oak, 15 cents for beech, and 16 cents for pine; and with creosote, 21 cents for oak, 50 cents for beech, and 43 cents for pine; while the average life

in years was 15, 9, and 12 for chloride of zinc and 24, 30, and 20, respectively, for creosote.

The cost of burnettizing sawed pine ties, 6 × 8 inches by 8 feet long, for the Southern Pacific Railway was 10 cents each in 1893, and a little over 6 cents in 1897, not including interest or depreciation. On the Atchison, Topeka, and Santa Fé Railway the cost of zinc-tannin treatment has been about 15 cents, and for 1892 about 14 cents, and 13 cents for burnettizing. In 1897 the cost of the zinc-tannin was 11.6 cents, no interest or depreciation being included.

While the above facts taken from Mr. Curtis's paper relate to railroads wholly rather than to pavements, they illustrate clearly the effect of a chemical treatment upon wood as a preservative; and while the deductions as to the action of wood in railroad-tracks would not necessarily follow when applied to wood pavements, they are still of value, and are the best data available at present.

The so-called creosote oil of commerce does not contain any creosote. The creosote odor that comes from the oil is caused by carbolic acid, which, being soluble, exerts very little preservative influence upon the wood.

Creosote is the product of the destructive distillation of wood, while the ordinary creosote oil is obtained from coal.

The Norfolk Creosoting Co. of Norfolk, Va., has issued a trade publication upon the subject of creosoting. It is stated there that the preservation of timber consists of two distinct operations, the preparation of the wood and its impregnation with the preservative. It is necessary to remove from the wood all portions of the tissue that are subject to fermentative action. This consists of the extraction of the liquids and semi-liquids occupying the interfibrous space, without softening the cement binding of the fibrillæ, or bundles of cellular tissue, forming the solid or fully matured part.

If this step is conducted at too low a temperature or for too short a time, only the sap or liquid part nearest the surface will be extracted, leaving insufficient space for receiving the preservative. If, on the other hand, the operation be carried on at too high a temperature or for too long a time, the resinous portions of the bundles of fibrillæ will be softened and the wood lose its elasticity in just the proportion that the coherence of the fibrillæ

is lessened. The temperature should never be less than 212° nor more than 266° F.

The following specifications for creosoting are from the publication above referred to:

"*Oil.*—All oil shall be the heavy or dead oil of coal-tar, containing not more than 1½ per cent of water, not more than 5 per cent of tar, and not more than 5 per cent of carbolic acid.

"It must not flash below 185° F. nor burn below 200° F.; and it must be fluid at 118° F. It must begin to distill at 320° F., and must yield, between that temperature and 410° F., of all substances less than 20 per cent by volume.

"Between 410° and 470° F. the yield of naphthalene must be not less than 40 nor more than 60 per cent by volume. At two degrees above its liquefying-point it must have a specific gravity of maximum 1.05 and minimum 1.015.

"*Processes of Treatment.*—Seasoning: This is to be accomplished by subjecting the timber to the action of live steam for a period of from five to seven hours at a pressure of 35 to 55 pounds per square inch, the temperature not at any time exceeding 275° F. unless the timber be water-soaked, in which case it may reach 285° F. for the first half of the period. At the expiration of the steaming the chamber shall be entirely emptied of sap and water by drawing off at the bottom. As soon as the chamber is cleared of all sap and water a vacuum of not less than 20 inches shall be set up and maintained in the chamber for a period of from five to eight hours, or until the discharge from the vacuum-pump has no odor or taste, the temperature in the chamber being maintained at between 100° and 130° F. The chamber being again emptied of all sap and water, the oil is to be admitted, the vacuum-pump being worked at its full speed until the chamber is filled with oil. As soon thereafter as is practicable such a pressure shall be set up as shall cause the entire charge of timber to absorb —— pounds of oil within —— per cent, more or less (at a minimum penetration of 1½ inches in round timber for a treatment of 12 pounds of oil per cubic foot, constituting a basis for determining the penetration due to a treatment of any specific quantity of oil), —— inches from all exposed surfaces. The depth of the penetration being ascertained by boring the

treated piece with an auger making a hole not more than $\frac{5}{8}$ inch in diameter, such pieces as are found not to have the required penetration being returned to the chamber with a subseqent charge for further treatment."

The early wood pavements were popular when first laid, but they decayed so soon that their popularity soon waned. But when it became known that chemical treatment would preserve them from decay they soon regained their place in the feeling of the general public. They are almost entirely noiseless, resilient, pleasing to drive over, but slippery. This last is a fault, but almost the only one that can be ascribed to these pavements. When dry, however, they are not slippery, and if care is taken not to lay them on too steep grades and to sprinkle them with sand upon the damp and frosty days, the trouble from slipperiness can be reduced to a minimum. Where streets are subjected to a heavy and continuous traffic wood should not be used on grades steeper than 2 per cent. For some years treated wood has been considered a standard material.

The success of the Indianapolis pavements was such that capitalists became interested in wood pavements, and a scheme was devised for treating the blocks with a composition made up of equal parts of creosote and resin. The idea was that the creosote would preserve the blocks from decay and the resin would prevent evaporation of the oil. The first pavement of this character was laid in 1900 on the west side of Tremont Street, Boston, opposite the Common. This pavement was so satisfactory that similar pavements were laid in other cities of the country in a short time, and treated blocks soon became popular as a pavement material. In course of time the cost of resin increased, so that an attempt was made to reduce the price of the pavement by making the composition 75 per cent creosote and 25 per cent resin. It was afterwards thought, however, that by using an oil of heavier specific gravity the use of the resin could be discontinued altogether, and it has been several years since resin has been used.

In the construction of treated wood pavements engineers vary greatly as to the proper procedure, and there is probably more difference of opinion as regards proper construction with this material than for any other class of pavement. The principal

items to be considered in the construction of a wood pavement, and upon which opinions differ, are the kind of wood, the character of the oil for treatment, the quantity to be used, the proper filler for the joints, and the cushion upon which the blocks shall be laid. It is assumed that this pavement, like all others, is to be laid upon a proper concrete foundation.

Kind of Wood.—So far as actual wear is concerned, there is probably no question among engineers that long-leaf yellow pine is the best material. It is, however, a comparatively hard wood and is consequently more slippery than the softer varieties. It is also growing more expensive from year to year, and efforts have been made to discover, if possible, other woods that would be suitable for light if not for heavy traffic.

In 1906 an experimental pavement made up of different varieties of wood was laid by the Forest Service of the U. S. Department of Agriculture in Minneapolis, Minn. The woods used in the improvement were long-leaf pine, Norway pine, tamarack, Douglas fir, Western larch, white birch and hemlock. The long-leaf pine was included so as to provide a standard for comparison with the other varieties. A complete description of this experiment and the result after 4 years are given in Circular 194, U. S. Department of Agriculture, issued January 16, 1912. The blocks were treated with 16 pounds per cubic foot of coal tar-oil having a specific gravity of 1.09 at 20° C., except that the oil used in the white birch and Western larch blocks had a lower specific gravity, so that 20 pounds per cubic foot was used in the case of these species to compensate as nearly as possible for the discrepancy in the specific gravity between the oil used and that specified. The conclusion reached after the examination of the pavement, 4 years after it had been laid, was that " the species used will be tentatively grouped in accordance with the results of this inspection in the order of their value for creosote oil-paving material as follows:

" 1. Long-leaf pine.

" 2. Norway pine, white birch, tamarack, Eastern hemlock.

" 3. Western larch.

" 4. Douglas fir."

Black gum wood has also been used to a certain extent, but it is not as favorably looked upon as the pine.

In Paris a wood known as the " Pine of Landes," grown on land belonging to the city, is used. In Westminster, London, the specifications say, " All soft wood blocks shall be cut from good quality pine deals from Baltic, White Sea or Archangel ports." London also uses hard Australian woods under certain conditions. It is probable that in this country yellow pine will continue to be the material most used until some other species has proven satisfactory.

Treatment.—It seems to be an accepted fact by practically all wood preservers that the best material for this purpose is creosote oil. This oil was originally made from coal tar. However, since the manufacture of water-gas, oil made from water-gas tar has been advocated for years as well as the coal-tar product. The function of any preservative for wood blocks for paving purposes is not only to keep the blocks from decay, but also to make them waterproof, so that the pavement when laid shall be stable, not becoming loose in dry nor bulging in wet weather. It is not sufficient that the properties should exist when the pavement is first laid. A yellow-pine block that is kept free from decay will last for an extremely long time on a residence street, if wear and tear only are taken into account. For that reason it is highly important that the composition of the preservative shall be such that it will maintain its qualities as long as possible, both as to its septic and waterproofing qualities. Much discussion on this subject has taken place during the last few years. In a paper entitled " Creosote Specifications and Analysis," presented at the eighth annual meeting of the Wood Preservers' Association, held in Chicago January 16 to 18, 1912, Mr. Hermann von Schrenk says:

" It will not be necessary to dwell on the history of the use of coal-tar creosote, nor to present proofs as to its value as a wood preservative. For years this substance has generally and justly been regarded as the best wood preservative, and the increasing quantities used plainly indicate that this is universally recognized '

Further on in the paper he continues:

" Reverting to the statement that all parts of coal tar are

antiseptic, and therefore acceptable, it appears, when their stability is considered, that many of them should be ruled out. In view of the different composition of creosote oils obtained from different coals and countries, and in view of the general value of all compounds from an antiseptic standpoint, furthermore in view of the rapid disappearance of the low-boiling fractions (meaning thereby those distilling below 235° C.), what more can be said for a good creosote oil than that it must be a coal-tar product and have as small a percentage of low-boiling compounds as possible?"

Still further on the paper, discussing the specific gravity of oil, he says:

"Reference has been made to a third requirement of creosote oil, namely, waterproofing qualities. This has arisen recently in connection with American paving-block treatment. Specifications were written calling for very heavy 'creosote oil'; in many instances the specific gravity called for was 1.10 or more. Anyone familiar with coal-tar creosote realizes that such a requirement is impossible, because there is no coal-tar creosote (at least none in quantity) having such a high gravity. The heaviest oils known rarely exceed 1.082. To make an 'oil' with a specific gravity of 1.10 or more meant that coal-tar pitch had to be added in considerable quantities to creosote, and this is what has been done and is now being done. The chief reason given for demanding such a heavy compound was that such an oil would make the blocks more or less waterproof. Personally I have very little regard for this claim. To discuss this subject fully would make this paper too long. Creosote will waterproof wood to a certain extent; the extent will be largely determined by the quantity injected. A piece of wood with 5 pounds of creosote per cubic foot will absorb very much more water than one with 15 pounds per cubic foot. The heaviest injections, however, will not entirely waterproof wood fibre. I have made a good many determinations under exact conditions, and fail to find any marked evidence for the waterproof claim. I believe that the lasting qualities of wooden paving blocks are dependent on similar factors as is the case with ties. A good heavy creosote will answer every purpose, as has long been demonstrated abroad and in many places

in this country. Where an engineer believes that his local requirements require an oil having a specific gravity of 1.10 or more, he can, of course, use same, providing that he realizes that such an oil can be obtained only by putting tar or pitch into his oil."

There seem to be two beliefs among engineers as to the requirements of oil for specific gravity, one class specifying a gravity of 1.03 to 1.05 or 1.06, and the other a gravity of 1.10, the latter recognizing the fact that the product specified is not an oil proper, but a composition made by adding to coal-tar oil sufficient tar to bring it up to the required gravity.

The author is of the opinion that by the use of a heavy gravity composition the blocks are preserved for a greater length of time than by the lighter gravities, believing that the lighter gravities must volatilize more rapidly than the heavy, and so lose to a certain extent their septic and waterproofing qualities. Regarding the kind of oil, it is held by some chemists that as good a composition for treating the blocks is made from water-gas tar as from coal-gas tar. This question can only be determined by experience.

Quantity of Treatment.—As will be noted, Mr. Schrenk says that "creosote will waterproof wood to a certain extent; the extent will be largely determined by the quantity injected." It is highly important that the wood be waterproofed as thoroughly as possible, both on account of present conditions and also that these conditions may be continued in the future, as upon that will depend the durability of the pavement. In European cities it is not common as a rule to use more than a 10 or 12 pound treatment, and in this country many cities use only 16 pounds per cubic foot. The author has always specified 20 pounds per cubic foot for pine, and in some cases 22 pounds for gum, the specifications for the Boroughs of Manhattan and Brooklyn, New York City, calling for these amounts. In addition to this requirement, and to a certain extent to satisfy the engineer that the requirement has been carried out, it is sometimes also specified that the pine blocks shall nor absorb more than 3 per cent of water after having been dried for 24 hours at a temperature of 120° and then immersed in water for 24 hours. Pavements under this requirement have been laid for 10 years in the Borough of Brooklyn and very little buckling or bulging has occurred, although no

expansion joints were used. The author believes, however, that as a general proposition it is safer to use an expansion joint.

Cushion.—It has been the practice in this country to allow either sand or dry cement mortar upon the surface of the concrete foundation in which to bed the blocks as they are laid. Some engineers advocate the use of sand, as it is claimed that a more even surface for the pavement can be obtained than by the use of the mortar. From his own experience the author believes that better results will be reached by bedding the blocks in a cushion composed of one part of Portland cement and three parts of sand mixed comparatively dry but with sufficient moisture to allow it to set. In parts of Europe the practice is to float the concrete to an absolutely smooth and true surface and lay the blocks directly upon this surface, bedding them simply in bituminous cement.

Joint Filling.—Three kinds of joint filler for wood blocks have been used: sand, cement grout, and bituminous cement. If sand is used, after the blocks have been laid the joints are filled with a very fine sand, just previous to the tamping or the rolling of the blocks. This filling is continued after the rolling until the joints are completely filled, and care should be taken for several days after the street is opened to traffic to see that the joints are kept full.

If a cement grout filler is used it is composed of one part of sand and one part of Portland cement, the blocks being laid close or rammed or rolled, and then the joints thoroughly filled with the grout. Unless sufficient time is allowed for the grout to become thoroughly set it will of course break up under traffic and be no better than, if as good as, sand.

Bituminous Filler.—Many engineers prefer the bituminous filler to either cement grout or sand. It is claimed that by the use of a bituminous cement each joint becomes an expansion joint, thus preventing any bulging of the pavement, and also that by its use the water is kept from soaking down into the joints and swelling the blocks at the bottom. It is claimed, however, that if, as often happens, the blocks "bleed," or the composition exudes from them, that the bituminous filler simply adds to the

nuisance caused by this exudation of the preservative, while a sand filler would absorb it to a certain extent.

With regard to all of the foregoing points, the specifications adopted in January, 1912, by the Organization for Standardizing Paving Specifications, permit the use of Southern yellow pine, Norway pine, black gum and tamarack; the preservative to be a product of coal gas, water gas or coke oven tar which shall be free from all adulterations and contain no raw or unfiltered tars, petroleum compounds, or tar products obtained from processes other than those stated; the specific gravity to be not loss than 1.10 nor more than 1.14 at a temperature of 38° C. Also, for a preservative to be a distillate of coal gas or coke oven tar to be free from all adulteration, and contain no raw tar, filtered or unfiltered tars, or pitches, petroleum compounds, or other products; to be completely liquid at 38° C., with a specific gravity of not less than 1.03 and not more than 1.08 at that temperature.

The quantity of treatment is 18 pounds per cubic foot for pine and tamarack blocks and 22 pounds for gum blocks; the amount in the pine and tamarack blocks to range from 16 to 20 pounds at the discretion of the engineer, according to local conditions.

For the filler it recommends that when the blocks are laid upon a sand cushion the joints between the blocks shall be filled with a suitable bituminous filler, and that when the blocks are laid upon a mortar or bituminous cushion the joints may be filled with sand, and also a cushion composed of one part of Portland cement and four parts of sand, the same to be sprinkled with water when spread, unless previously moistened; also, that under special conditions where the foundation may be exceptional, the sand or mortar cushion can be omitted and a bituminous coating spread upon the smoothly finished and thoroughly dry concrete base. It recommends an expansion joint along the curb ¾ inch in width and filled with a suitable bituminous substance.

The specifications for the Bureau of Highways, Borough of Manhattan, admit only long-leaf yellow pine, and provide that the blocks shall be treated with not less than 20 pounds of oil per cubic foot. The oil is described as a standard antiseptic waterproofing oil from which all the water has been removed by dis-

tillation, and which shall have a specific gravity of not less than 1.10 at 38° C. When distilled it shall not lose more than 35 per cent up to a temperature of 315° C., and the distillate between 255 and 315° C. shall have a specific gravity of not less than 1.02, the said specific gravity to be taken at a temperature of 60° C.

The specifications also provide that after treatment the blocks shall be dried in an oven at a temperature of 100° F. for a period of 24 hours, and when immersed in clear water for a period of 24 hours shall not gain in weight more than 3½ per cent. The specifications were adopted in 1909 by a committee composed of the Chief Engineer of the Board of Estimate and Apportionment, the Chief Engineer of the Finance Department, and the Chief Engineers of Highways of the different boroughs of the city.

It will be noticed that it is not stated that the oil shall be a product of coal tar. The specifications were made in this way because it was claimed that an oil such as that called for in the previous specifications could be produced by mixing a light coal-tar oil with water gas tar. While the engineers did not deem it advisable to admit an oil that was entirely a product of water-gas tar, they did not object to a certain percentage of it, and the specific gravity of the distillate between 255° and 315° C. was fixed at 1.02 in order that this dilution might not exceed 50 per cent.

It will also be noted that an absorption test is provided for the treated blocks. This requirement is probably in no wood block specification outside of the City of New York. It has, however, been in use there since the present wood pavements have been laid. No requirement for expansion joints has ever been in the New York specifications, and very little trouble has ever occurred from bulging, although some has, and it is the feeling of the author that the requirement for absorption, the fulfilment of which shows thorough treatment, has had much to do with preventing bulging or other deformation of the pavement.

The first treated wood pavements laid in the Borough of Brooklyn were treated with a preparation composed of one-half creosote oil (no required specific gravity) and one-half resin.

The blocks were required to have a specific gravity greater than and 1 not to absorb more than 3 per cent of water when immersed for 24 hours after having been dried for the same length of time at a temperature of 100° F. These pavements were laid without expansion joints and have now been in use nine years with practically no repairs and almost no bulging.

Laying the Blocks.

The concrete for a wood pavement should be made as smooth as possible in order that there may be no uneven bearing of the blocks. English specifications, as has been shown, require the surface of the concrete to be floated so that the surface shall be absolutely smooth when the blocks are laid directly upon it. In this country, however, it has been customary to spread a cushion of cither sand or damp cement mortar over the concrete to a depth of 1 inch in the case of sand and ½ inch in the case of mortar. In either event the cushion is brought to a true and even surface by the use of a template formed to the exact shape of the completed pavement. If mortar is used it must be mixed with as little water as will allow it to set, so that it will not be soft or mushy. Upon the prepared cushion the blocks must be set, the workmen standing on the completed work and not upon the cushion. Care must be taken to break joints uniformly and set the blocks up closely, both at the sides and ends. When a suitable amount has been laid, the joints shall be filled with the specified material and the blocks brought to a solid and even bearing by either rolling or ramming. If a pitch or cement filler is used, a preliminary rolling should be given before the pouring; if cement is used either in the joint or cushion, the rolling should be done as expeditiously as possible, and then the pavement left undisturbed until the cement has set.

CHAPTER XI

BROKEN-STONE PAVEMENTS.

As has been seen in the study of stone-block pavements, the developments led to a general reduction in the size of blocks. So with the irregular stone pavements, they, too, decreased in size as their use increased. While probably small broken stone were used in roads for many years previous, it was not until 1764 that what is known at the present time as macadam roads were first built systematically by M. Tresaguet, a French engineer, who was the first to adopt this plan, and it came into general use about ten years later. His method of construction as described by himself is as follows:

"The bottom of the foundation is to be made parallel to the surface of the road. The first bed of the foundation is to be placed on edge, and not on the flat, in the form of the rough pavement and consolidated by beating with a large hammer, but it is unnecessary that the stones should be even with one another.

"The second bed is to be likewise arranged by hand, layer by layer, and beaten and broken coarsely with a large hammer, so that the stones may wedge together and no empty space may remain.

"The last bed of 3 inches in thickness to be broken about to the size of a small walnut with a hammer on one side of a sort of anvil, and thrown upon the road with a shovel to form a curved surface. Great care must be taken to choose the hardest stone for the last bed, even if one is obliged to go to more distant quarries than those which furnish the stone for the body of the road. The solidity of the road depending on this latter bed, one cannot be too scrupulous as to the quality of the materials which are used for it."

The object of this lower course of large stone was to separate the wearing surface from the subgrade, rather than to form a foundation for the road.

This method as just described was practically that adopted by Telford some forty years later in England, the difference being principally in making the subgrade level and forming the crown with the stone itself, rather than making the base parallel to the finished surface of the road as Tresaguet did. The following is taken from Parnell's treatise on Roads, which gives Telford's specifications in detail:

"Upon the level bed prepared for the road materials the bottom course, or layer of stone, is to be set by hand in the form of a close, firm pavement. They are to be set on the broadest edges, lengthwise across the road, and the breadth of the upper beds is not to exceed 4 inches in any case. All the irregularities of the upper part of the said pavement are to be broken off by a hammer, and all the interstices to be filled with stone chips, firmly wedged together by hand with a light hammer. The middle 18 feet of pavement is to be coated with hard stone as nearly cubical as possible, broken to go through a 2½-inch ring, to a depth of 6 inches; 4 of these 6 inches to be first put on and worked by traffic, after which the remaining 2 inches can be put on. The work of setting the paving-stones must be executed with the greatest care and strictly according to the foregoing directions, or otherwise the stone will become loose and in time may work up to the surface of the road. When the work is properly executed, no stone can move; the whole of the material to be covered with 1½ inches of good gravel, free from clay or earth."

Parnell, in commenting on this last clause of covering the road with gravel, says: "The binding which is required to be laid on a new-made road is by no means of use to the road, but, on the contrary, is injurious to it. This binding by sinking between the stone diminishes absolute solidity to the surface of the road, lets in water and frost, and contributes to preventing complete consolidation of the mass of the broken stone."

A contemporary of Telford and a man whose name has been given to this class of roads, in the English-speaking world at least, was Macadam. He worked on very different principles, in that

he not only did not require the foundation-course, but stated that he considered it positively injurious. He enunciated the following principles as fundamental: "That it is the native soil which really supports the weight of traffic; that while it is preserved in a dry state, it will carry any weight without sinking, and that it does in fact carry the road and carriages also; that this native soil must be previously made quite dry and a covering impenetrable to rain must then be placed over it in that dry state; that the thickness of the road should only be regulated by the quantity of material necessary to form such impervious covering and never by any reference to its own power of carrying weight."

In some evidence given before a Parliamentray commission upon the subject of roads, soon after Macadam had taken up their reconstruction, he stated in answer to a question by one of the committee that he considered that 10 inches of well-consolidated material was sufficient to carry any load, and that without any reference whatever to the foundation. He also added that he would prefer a soft foundation to a hard one, going so far as to say that he would prefer a bog if it were sufficiently hard to allow a man to walk over it. It must be remembered that all of these roads were very different when first built from those of the so-called macadam roads of to-day, as they received no rolling whatever, but were consolidated wholly by traffic.

The question as to which is the better system, Telford's or Macadam's, is one that has been discussed for a good many years. It is hardly necessary to say that at the present time Macadam's idea of having a soft, yielding foundation for his road is not considered good practice. On the other hand, the foundation as described by Telford is expensive, and in roads of light traffic, with a good natural foundation, it would seem to be unnecessary. Where a particularly solid roadbed is required it is the custom of many engineers to build what is called the telford-macadam road, that is, it has a telford base with a macadam wearing surface. Macadam's own particular work, when he took it up, consisted of repairing old roads rather than constructing new, and it is said that he was so successful that in many instances the cost of reconstruction per mile was but little, if any, more than had been the previous cost per annum for maintenance, and it is also true

that the condition of the roads was very much improved. The roads built previous to his time were very crude, although containing an immense amount of material, but laid with an entire lack of scientific knowledge. Macadam describes this old process in vogue at that time as follows:

"The practice common in England and universal in Scotland in the formation of a new road is to dig a trench below the surface of the ground adjoining, and in this trench deposit a quantity of large stones; after this a second quantity of stones broken smaller, generally to about 7 or 8 lbs. weight. These previous pieces of stone are called the bottoming of the road, and are of various thicknesses, according to the caprice of the maker, and generally in proportion to the sum of money placed at his disposal. On some new roads made in Scotland in the summer of 1819 the thickness exceeds 3 feet.

"That which is properly called the road is then placed on the bottoming by putting large quantities of broken stone or gravel, generally a foot or 18 inches thick, at once upon it, and from the careless way in which this is done the road is as open as a sieve to receive the water which is retained in the trench."

This description allows one to understand the radical change made by Macadam when he inaugurated his system. It can be readily seen how, under any material amount of traffic, a road constructed in such a manner might soon become very rough and uneven and very disagreeable for traffic. When one thinks of building to take the place of these roads others with a maximum thickness of 10 inches and made up of stones which, according to Macadam's standard, could be easily placed in one's mouth (and which should not weigh more than 6 ounces), it can be readily understood that a Parliamentary investigation was quite in order before any great amount of money was expended in this work.

The trite saying that "Nothing succeeds like success," however, was just as true then as it is now, and it required but a short time, and very little testimony, to satisfy even the Parliamentary committee that the money was well expended. Macadam utilized the old material already in place, and by breaking it as he did, by hand, gave employment to a large number of people, many of whom, as he says, were old men and women.

In speaking of the relative merits of macadam and telford roads, Mr. A. J. Cassatt, in a letter to the Commissioner of Public Roads in New Jersey, says that as a result of his experience with both systems, commencing with the telford, he is very strongly in favor of the macadam under any circumstance and for any kind of subgrade. He says that during the long periods of dry weather in the summer the roads are apt to disintegrate and the surface become covered with loose stones, and that this occurs more frequently, and to a greater extent, in the telford than in the macadam. Another objection he makes is that the surface stones wear off much more rapidly with the solid telford base than with the macadam, which always wear smoothly and uniformly except when the bond is broken in the early spring, when the frost is coming from the ground.

Although the macadam and telford roads are taken up under the head of Pavements, they should not, strictly speaking, be classed as such, as they are not suitable for city streets, although used to a considerable extent in many large cities on account of their cheapness. Their principal objection is their extreme dustiness, requiring almost constant sprinkling, which causes a great amount of mud, and this is entirely out of place in a city street. Any one doubting the advisability of the macadam for an urban district should visit the Back Bay section of Boston on a windy day in winter, when the ground is free from snow and the weather too cold to permit sprinkling, and he will be thoroughly convinced. As long, however, as a law remains on the statute-books allowing a property owner to pay for the first cost of a pavement and compelling the city to pay for all future pavements, so long will macadam streets be laid, as thrifty taxpayers will be willing to undergo the discomfort of the dust for the sake of avoiding a heavy assessment for a good pavement.

The question involved in the construction of a macadam street in a city is very different from that governing the construction of a suburban road; and while the general principle of the construction is necessarily the same in both cases, what would be proper for one might be decidedly improper for the other.

Macadam Streets.

Before any street is macadamized in a city, it should be sewered and the connection-pipes all laid, so that the subject of drainage would be taken care of in that way. In some soils, however, it might be necessary to lay supplementary pipes to take care of this drainage; but it is fair to assume that the surface-water is provided for before the street is ordered improved. This, however, is not always done, and when an engineer is obliged to construct a macadam street in an unsewered section, he must make special provisions for both surface- and sub-drainage. Under such conditions, however, no macadam pavement should be laid as a permanent improvement, but only to make a temporary roadway, and not then for the entire width between curb-lines.

If a street without sewers is curbed, guttered, and paved for its entire width between curbs, the surface-water is necessarily led to the low points of grade, and very often with no means whatever for taking care of it. If the soil consists of sand and gravel, temporary provision can often be made by digging large cesspools at the curb corners and stoning them up loosely, so that the water may soak away gradually. This, however, is a temporary expedient, but is the only thing that will afford temporary relief, even. If, on the other hand, gutters are not laid, and only the central portion of the roadway improved, the water will run to the sides and much of it soak away in the ground, rather than be concentrated at one point. If, however, the streets are well sewered, with catch-basins at low points of the grade, the question of surface-water is very simple, and if drains are necessary to carry off the water from the subgrade, they can be connected with the catch-basins.

Assuming, then, that the city street is sewered and satisfactorily drained, the questions of quality, size, and thickness of the material, as well as the base, must be determined. Macadam's theory that a road on an elastic foundation would last longer than one on a solid base has caused considerable amusement among engineers of the present time, yet he was unquestionably correct. It is a well-known fact to all railroad engineers that a track laid in a rock-cut, with the ties resting on the solid rock, will wear out much more quickly than when laid on a roadbed that is somewhat elastic, and also that the wear and tear of the rolling-stock will

be appreciably greater. This is because the rails are perfectly rigid and they themselves must take up the impact of the car-wheels, which otherwise is partially transferred to the elastic roadbed.

It is also well known that if a stone resting on an anvil or solid rock be struck a blow with a heavy hammer, it will break, whereas if resting on soft earth, it will remain unharmed under the same blow, but will be driven into the soil. In the one case, the reaction of the blow is all taken up by the stone which, in consequence, is broken. On the other hand, the impact of the blow is mainly taken up by the resistance of the soil and the stone remains unharmed. It is for this reason that both the rolling-stock and the iron of the railroad on a rigid base suffer more than when the roadbed is slightly elastic. For this reason, too, a road laid in the manner described by Macadam as to base will last longer than one that has a solid foundation, but it will not be as smooth, nor will it maintain its form as well under traffic.

It must be remembered, whenever the present macadam roads are compared with those built in the days of Telford and Macadam, that the vehicles were expected to do the work which in these times is performed by a steam-roller, and that what is required at the present is a good road as soon as it is constructed, as well as one that is durable; so that in a city street care must be taken to see that all soft or perishable matter has been removed from the subgrade, and the foundation prepared of some material that can be consolidated under the roller.

It should be understood, too, that any macadam pavement (and in this connection and hereafter the term "macadam" will be applied to all pavements with the wearing surface made up of small broken stone, the word telford being applied only to the base) must consist, as do all other pavements, of a foundation and wearing surface. Any material that is imperishable and can be easily consolidated under the roller is suitable for the foundation, and its selection must depend upon the material at hand. Assuming, however, as is generally the case, that all the material for a city street must be brought from the outside, where transportation charges are comparatively large, the material that gives the best result is the one that should be selected as a rule. The thickness

of the foundation depends upon the amount of traffic the street is to sustain.

Many engineers differ materially in the thickness which is considered proper for a macadam pavement, but for a street that has a moderate amount of traffic, and where the pavement is to be permanent, it would seem that the total thickness of 8 inches would give the best results. The size of the stone for the foundation-course is not so material, provided it will comply with the conditions of the principle laid down before, that is, that it will thoroughly compact under the roller. Too large stones and those of irregular shape will not give good results in that respect. The size most commonly adopted is specified in a general way as being one that will pass through a 3-inch ring. This will give a stone slightly exceeding 3 inches in some dimensions, but generally not enough to do any harm. It should be solid and of an imperishable character.

In determining the thickness of the wearing surface, it must be considered not only how fast the surface will wear out, but also how much it can be permitted to wear away without the road becoming too rough. It is well known that a broken-stone road must wear unevenly, and that after it has worn down in that way to such a depth that the surface has become so rough that new material must be added, any extra depth that has been given to the wearing surface will be wasted. Thus, if the general wear of the road has been 3 inches and the surface is in such condition that it must be entirely gone over and brought up to the original grade, the amount of wearing surface below 3 inches is of no benefit; and if the wearing surface were 6 or 7 inches, half of it would have been wasted, so that it would seem that the proper apportionment is 8 inches of material divided equally between the wearing surface and the foundation.

Character of the Wearing Surface.

In determining the character of the stone that is subject to traffic different conditions entirely must be considered from those governing for the foundation-course. If the stone is hard and wears but little under traffic, the pavement will be rougher than if laid with a softer stone, but will be more durable. It will also be less dusty. Without any question trap-rock is the best material

for the surface of a broken stone pavement if its wearing qualities only are taken into consideration. If, however, the travel on a street is to be light and a smooth, easy surface is required, a pavement composed of limestone or some other soft material will often be more satisfactory. Limestone has greater cementitious properties than trap-rock, and will maintain a much more pleasing surface under light traffic.

The size and shape of the stone, too, are of great importance. In shape they should be as nearly cubical as possible, and whatever the size it should be uniform. Small stones wear out much more quickly than large ones. If they are mixed indiscriminately, and the smaller pieces ground into dust and blown away, the surface is often left so rough that the wheels of vehicles practically jump from one stone to another, rather than roll over a continuous smooth surface. This uniformity in the size of the stone is of course more important with a harder material than with a soft, as under light traffic trap-rock wears very slowly. The actual decision, then, as to which is the proper material for any particular case must be decided by the existing conditions, and while it must be admitted that the limestone makes the most agreeable pavement for light traffic, it must also be remembered that the great freedom from dust of the trap-rock road with light travel is a great argument in its favor.

It should be considered, also, that when, as in the case of the city streets, the material must be brought from a considerable distance, and that the freight on a ton of poor material is the same as that on a ton of good material, ultimate economy will often determine which is the proper stone. It will be best, therefore, whatever material the stone is composed of, to make the size for the top course as near 1½ inches in every dimension as possible.

Construction.

After having decided upon the quality and amount of material required, the next question is the character of construction.

Upon a roadbed which has been prepared as previously described the stone which is to form the foundation-course should be spread in such thicknesses as to be of the required depth after rolling. It is the custom of some engineers to roll the first course

until it is thoroughly consolidated. Others, however, consider that it is only necessary to roll it enough so that it will not be further compacted under the rolling of the wearing surface, but will leave a somewhat loose rough surface, so that the top course will bond with it and the entire pavement be of one piece rather than of two thicknesses placed one upon the other. This latter is generally considered the better method, although the first has many strong advocates.

After the stone composing the second course has been evenly spread to the required depth, it should be rolled by a roller until it has been almost entirely compacted before the addition of any binder.

This is important, as the voids of the stone should be made as small as possible, so that no great amount of binder will be required. If the binding material be scattered over the stone before it has been rolled, the process of rolling will cause it to mingle with the stone and fill the voids and separate the individual stones from each other so that they will roll one upon the other without consolidating, which is producing exactly the reverse result of what is desired. The propriety of using a binding material at all has been questioned by many engineers. Mr. A. F. Rockwell in a work called "Roads and Pavements in France" says the best engineers in France are not in favor of any binder, according to the principle that, other things being equal, a road is so much the better the less fine material it contains. He further says that the passage of a 10-ton steam-roller forty or fifty times over a given point renders all binding material superfluous and compacts the stone so thoroughly that it becomes a mass nearly as solid as the rock itself.

If this be true in France, the experience of American engineers with trap-rock has been very much to the contrary. In the early roads in the time of Macadam, as is well known, the practice was to allow traffic to consolidate the road and no binder was used, but, about 1830, rollers came into use, at first drawn by horses, but afterwards propelled by steam, and then the question of finishing the surface assumed a different aspect.

Mr. Deacon, an engineer of Liverpool, in speaking of the effect of binding material says: "Under a 15-ton steam-roller, preceded

by a watering-cart, 1200 yards of trap-rock macadam without blinding can only be moderately consolidated by 27 hours' continuous rolling. If blinded with trap-rock chippings from the stone-breaker, the same area may be moderately consolidated by the same roller in 18 hours. If blinded with silicious gravel from $\frac{3}{4}$ inch in size to a pin's head, mixed with about $\frac{1}{4}$ part macadam sweepings obtained in wet weather, the surface may be thoroughly consolidated in 9 hours. Macadam laid according to the last method wears better than that laid by the second, and that laid by the second much better than that laid by the first."

English engineers, and American as well, think that it is necessary to use some binding material in order to get satisfactory results; arguing that in case of consolidation without binder being added, the stones will not consolidate until a certain amount of dust has been worn from them by the attrition of the roller, and that if an outside binder be used, the road will be as solid and a great amount of wear of the stone saved for traffic.

Just how much binder will be required depends upon its character. The less that is used, provided good results can be obtained, the better. It should be scattered over the surface of the road in advance of the roller, and not dumped in piles and then spread, as in the latter case too great an amount will almost always be used in spots. The sprinkling-cart should follow the spreading of the material on the road, washing it into the voids, and the sprinkling should be immediately followed by the steam-roller. Care should be taken not to cover at any time the entire surface, as the binder would then serve as a cushion for the stone and prevent the wheels of the roller from acting directly upon the surface. This action of spreading the binder, sprinkling and rolling, should continue until the road is thoroughly consolidated.

If a surplus of binder is used, it not only prevents the stone from being properly consolidated, but after the traffic is allowed upon the street, and it begins to receive its consolidation from it, this surplus binder is forced up through the interstices of the stone of the surface and forms mud in wet weather and dust in dry, and must be constantly cleaned from the surface until the street has become consolidated by traffic.

Just how much rolling is required to make a solid roadbed

depends upon the solidity of the foundation, the character, size, and shape of the stone, and the character and amount of binder used. Referring to the principle of Macadam that a road will wear out more quickly with a solid than with an elastic foundation, it is equally true, and for the same reason, that a macadam road will be consolidated much more quickly if the subgrade is unyielding. In such cases the action of the roller is direct upon the stone and its work is much more quickly accomplished. This is often seen when macadam is built in part upon an old roadbed and in part upon an ordinary earth base. The difference in the amount of rolling required on each is very marked.

The character of the stone itself, however, is an important factor, as the softer the stone the quicker it consolidates. Limestone, for instance, with a binder of sand or limestone screenings will become compacted under less than one-half the amount of rolling required with trap-rock of the same size.

The size and shape of the stone also have an important bearing upon the labor of consolidation. If the pieces be cubical and of approximately the same size, they wedge closely with each other and become thoroughly compacted; whereas flat stones will continually tip under the roller and be compressed without being bound together.

The proper material for binding has been discussed to a considerable extent. When it is considered that the object of the binder is only to serve as a cementing material to hold the pieces of stone together, and at the same time make the surface water-tight, it would seem that the material which would serve this purpose with the least amount of rolling would be the best, because the cheapest, if the first cost of each should be the same. Sand, limestone screenings, and trap-rock screenings, as well as certain kinds of clay and loam, have all been used in different places and by different engineers as binding material. Ordinarily sand is the cheapest, as it can generally be found nearer to the work than the stone of which the pavement is composed, but it produces a road that will be very dusty under traffic, as, in order to possess any cementing properties, it must contain a certain amount of loam. Clean, sharp, fine sand will give no binding effects, as the pieces of stone will simply roll in the sand without consolidating.

Limestone screenings give excellent results, as they possess in themselves first-class cementing properties and give a hard and smooth surface to the road. If, however, the wearing surface is composed of trap-rock, most engineers wish the binding material to be composed either of trap-rock screenings or a mixture of trap-rock screenings and sand. Mixed in the proportion of 3 of screenings to 2 of sand, good results can be obtained.

Trap-rock in itself has very little cementitious value. If the binder be composed entirely of this material, it will require a great amount of rolling and a free use of water, but the result will be a hard, compact, durable road. It will not be so elastic as the limestone, but more durable. It will also require much more rolling.

The different qualities of limestone vary much in the amount of rolling required. The so called Tomkins Cove limestone, of which a great amount is used in the vicinity of New York City, has a wonderful cementing value and is easily made into a smooth, compact road. It breaks with a very nearly cubical fracture and is an almost ideal stone for a light-traffic road, as it always wears smoothly and presents a pleasing surface to vehicles; but from the very fact that it is easily bound and wears smoothly, it wears more rapidly than the other stones and consequently is not as durable upon heavy-traffic streets.

The amount of rolling that has been actually given in the construction of different streets varies greatly. Mr. Rockwell, in his work previously referred to, says that, assuming a layer of stone to be 3 inches thick and that a 10- or 12-ton roller is used, it is sufficient, with ordinary limestone, for the roller to pass over the surface 50 times, with granite 50 to 75 times, and with porphyry or trap 90 to 100 times. He adds that the amount required increases with the thickness of the layers, but not in proportion to the thickness, and that it is more if the stones are rolled dry than if they are wet.

American engineers, in specifying the amount of rolling required, generally say that the street shall be rolled to the satisfaction of the engineer in charge. In France the engineers have attempted to be somewhat more specific and have sought to measure it by the number of ton-miles per square yard, ranging

ordinarily from 0.4 to 0.6 ton-mile per yard. This, however, while it takes into account the weight of the roller, does not consider its speed; that is, a 10-ton roller passing over a street at the rate of 4 miles an hour would, according to that rule, have twice the efficiency of one moving at the rate of 2 miles per hour, but it is hardly probable that in practice that result would be obtained. At the same time, a roller moving at the rate of 4 miles an hour would probably do much more effective work than one moving at the rate of 2 miles, but there seem to be no specific data whatever to be obtained on this particular point. A standard, however, cannot be set up that will be satisfactory without taking into consideration both the speed and weight of the roller.

In a piece of work containing about 18,000 square yards of macadam, composed of two courses each 4 inches in thickness, a careful account of the rolling was kept, and the average amount rolled per day was almost exactly 200 square yards, the material being limestone for the first course and trap-rock for the second, with trap-rock screenings for binding material. Wherever, as in this case, the wearing surface and binding material are both composed of trap-rock, the binder must be practically a flour when the road is being finished. If it be coarse, the stone will not be cemented together; but if thoroughly rolled and wet so that the trap-rock flour is flooded, it will form a paste which, when dried out, will make a smooth, solid, and impervious surface. If the traffic on such a street be light, the pavement will probably pick up slightly under travel at first; but if it be rerolled in a short time after being opened to traffic, it will take its final consolidation and prove very satisfactory.

A certain road in Morris County, N. J., was built 12 feet wide of trap-rock, in two courses of 2½ and 1½ inches in thickness respectively, and finished with trap-rock screenings. This was compacted at a rate not to exceed 200 square yards per day.

In a discussion on road-building before the American Society of Civil Engineers in the latter part of 1898, Mr. E. W. Harrison of Jersey City, N. J., detailed to some extent the construction of the Hudson County Boulevard in New Jersey. This road was theoretically 12 inches deep with an 8-inch telford base and 4 inches of macadam, all of trap-rock. The macadam was made up

of two courses of $2\frac{1}{2}$- and $1\frac{1}{2}$-inch stones that would pass a $2\frac{1}{2}$-inch ring, and the surface was finished with trap-rock screenings, except in one portion where a small amount of clay was used between two layers of stone. Water was used freely and, according to the records kept of the rolling, the road had been gone over from 100 to 115 times.

In a paper on the Construction and Maintenance of Roads, presented to the American Society of Civil Engineers in 1879, Mr. E. P. North mentioned some repairs on the Southern Boulevard, New York City, where trap-rock broken to pass a 2-inch ring was laid 6 inches thick in one course, and 38.2 hours' rolling was given per 1000 square yards. He says: "Allowing the speed to have been $1\frac{1}{2}$ miles per hour, the work done on it amounted to 0.859 ton-mile per square yard and 5.177 ton-miles per cubic yard. 201 trips were made over the surface. The work was done in July and August, and a little less than 0.6 of a cubic foot of water per square yard was used for compacting and puddling. About $\frac{1}{3}$ screenings were added."

In a consular report it is stated that in Dresden a steam-roller weighing from 10,000 to 15,000 kilograms can compact from 80 to 100 cubic yards per day.

The amount of binder required to properly consolidate a road can be approximately estimated. Assuming the voids in the stone, as it is ordinarily delivered on the street, to be 45 per cent, and that under the action of the roller these voids will be reduced one-half, there will still remain 22.5 per cent voids which should be filled by the binder in order to have the road thoroughly solid and compact. This would give, then, approximately 25 per cent of the amount of stones spread loosely on the street to fill voids. Any amount very much in excess of this would seem to indicate that the road was not thoroughly compacted unless an appreciable quantity was left upon the surface. In carrying on the rolling the work should be begun at the sides, working towards the centre. Otherwise the street when completed is liable to be more flat than is desired.

Crown.

The principle governing the amount of crown to give a macadam street is somewhat different from that governing one of stone or asphalt. While the surface of a macadam road should be made solid and impervious to water, it is not always done, and the street should receive as much crown as possible without having a tendency to drive traffic to the centre of the street. The element of slipperiness which must be considered on the side slope of a hard-surface street can be entirely eliminated on the macadam. Then, too, the water should be carried from the roadway into the gutter as quickly as possible to prevent any washing of the surface. This, on steep grades, is very important, as, in a heavy storm, water running over the surface of the macadam will do much more damage than a great amount of traffic, so that, contrary to the rule for the stone pavement, the crown of steep grades should be greater than that of light ones.

The cementitious properties of stone, while very important, have not received much systematic investigation, especially in this country. The Massachusetts Highway Commission some years ago, however, made experiments to determine this. The test which was adopted is the impact test, to which briquettes made of the dust of the different kinds of stone to be tested are subjected. These briquettes are made of the dust that has passed through a screen with 100 meshes per inch and is obtained either from the abrasion test or by specially powdered stone. The briquettes are circular in section, 0.98 inch in diameter and the same in height.

The dust is placed in a metal die of the proper dimension, and mixing with it enough water to moisten the dust (0.24 cubic inch), a closely fitted plunger is inserted on top of the wet dust and subjected to a pressure of 1422 pounds per square inch. The weight of the dust varies with the density and compressibility of the stone, generally requiring about 0.9 ounce of dust to make a briquette of the above dimensions. Two weeks should be allowed for the briquettes to dry, at the ordinary temperature of a room.

A machine for testing these briquettes consists of a hammer weighing 2.2 lbs., arranged like a hammer on a pile-driver, on two

vertical guides. The hammer is raised by a screw and dropped automatically from any desired height. It falls on the plunger, which rests upon the briquette to be tested. The plunger is bolted to a cross-head and guided by two vertical rods. A small lever carrying a pencil at its free end is connected with the side of the cross-head by a link motion arranged so that it gives a vertical movement to the pencil six times as great as the movement of the cross-head. The pencil is pressed against the drum, and its movement is recorded on a slip of paper fastened thereon. The drum is moved automatically through a small angle at each stroke of the hammer. In this way a record is obtained of the movement of the hammer after each blow. The standard fall of the hammer for the test is 0.39 inch, and the blow is repeated until the bond of cementation of the material is destroyed. The final blow is easily ascertained, for, when the hammer falls on the plunger, if the material beneath it can withstand the blow, the plunger rebounds. If not, the plunger stays at the point to which it is driven. The automatic record which is obtained from each briquette is filed for future reference. The number of blows required to break the bond of cementation, as described above, is taken as representing the binding power of each stone, and is so used in comparing this property in road materials.

Another material that is used in the vicinity of New York City for binding and for surface covering is Roa Hook gravel. This material comes from up the Hudson River and is possessed of remarkable cementitious properties. It is found in sizes that are large enough to make the roadbed complete if desired, and when screened to the desired size makes the finest finishing for any macadam road. It has been used to a great extent on the driveways of Central Park, Manhattan, and Prospect Park, Brooklyn, and makes a surface that is probably as good as, if not better than, any other finishing material to be obtained in this country. Because it is easily bound and cemented it wears rapidly, and on account of its actual cost and its rapid wear it makes a doubly expensive material. It is a luxury, and for park driveways or bicycle paths it forms a surface that cannot be improved upon.

Finishing the Roadway.

The amount of fine material that is to be left upon a finished roadway is something upon which engineers differ. If any appreciable quantity remains, it receives the action of the traffic and, acting as a cushion, prevents to a certain extent the wear of the stone; but it will be excessively dusty unless sprinkled, and if sprinkled enough to prevent dust, is liable to form mud. On the other hand, if only enough is left to fill the interstices, the action of the traffic comes directly on the stone, and the wear is continual with the amount of traffic. It would seem better, therefore, to put on a quantity that will actually cover the surface of the road, and not very much more, and when this amount becomes worn down or blown away renew it. In this way a less amount of sprinkling will be required, the wear on the pavement will be reduced, and as little dust as possible result from the traffic.

Sprinkling.

After the stones have become compressed and the binder has been applied, the road should be constantly sprinkled with water at the time of the rolling, and continued as long as the rolling is in progress. The water is necessary both to wash the binder into the interstices of the stone, and also to aid it in cementing the individual stones together. If the work can be carried on during a mild rain, excellent results will be obtained; but should excessive rain or excessive sprinkling at any time cause the roadbed to become soft and yielding, the rolling should be at once stopped until the subgrade has had sufficient time to dry out; for with a soft roadbed the rolling will not only do no good, but it will absolutely do harm, as the earth under the stones will be formed into mud by the action of the stones in contact with it, and the mud will be gradually forced up between the stones, which will cause the road to be loose even after it is dried out and has been rolled. Continual sprinkling, too, shows whether the road has been made water-tight, as the wave which the engineers generally specify shall form in front of the roller before the rolling shall cease will not be produced if the road is porous and allows the water to soak away.

Gutters.

On any street that is paved with macadam, gutters of some sort must be provided, as there is probably no action that will cause more disintegration or greater injury to macadam than water flowing over it; so that a runway for the water must be provided of a different material if the street is paved from curb to curb, or, if no curb is set, to provide a shoulder for the gutter. This matter, however, will be taken up in detail in a subsequent chapter.

Fig. 24 represents a cross-section of a macadam pavement.

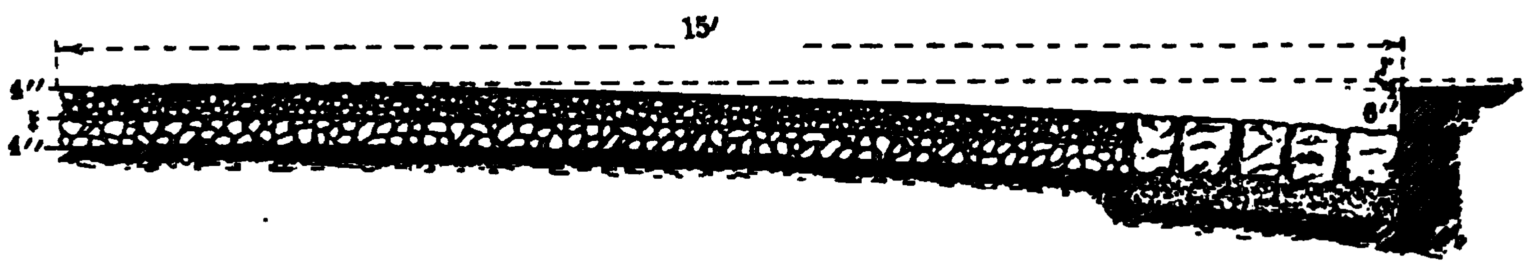


Fig. 24.

Specifications.

The city of Providence, R. I., has had a large amount of streets paved with macadam which have given satisfaction. The stone is purchased by the city, and the construction of the pavement carried out by day's labor. The following is taken from the instructions issued by the City Engineer to the foreman having charge of this work:

"If the subgrade is too sandy to admit of rolling, cover it with a thin layer of loom or gravel of sufficient thickness to permit rolling. Pave the gutters in a sand bedding, and back them well with coarse-sized broken stone; the paving and backing to be thoroughly rammed.

"Put on the roadway a layer of medium-sized broken stone; this layer is to be so placed as to leave the roadway surface true to section and about $2\frac{1}{2}$ inches below finished surface after compacting.

"Roll with the steam-roller until this layer is shaped to given section and sufficiently firm to admit of driving over without picking up; then put on the roadway a layer of broken stone of sizes varying from one-half to one and one-quarter inches; this layer to

be so placed as to leave the roadway surface true to section. Roll thoroughly with the steam-roller, the road metal to be kept damp while rolling. If open spaces appear in the stones when finishing rolling, put on sufficient fine stones to just fill the open space. The roadway is to be left true to section when finished."

Boston, Mass., is another city which also has a large number of macadam streets, many of them in the heart of the city, and some of them with very steep grades. The following is taken from the Boston specifications for macadam with telford base, as far as relates to the construction of the roadway:

"SECT. 6.—*Telford Base.*—(*a*) In the excavation for the roadway is to be laid the telford base, made as follows: Sound, hard stones, four inches to ten inches in width, eight inches to twenty inches in length, and not less than ten inches in depth, are to be placed by hand, vertically on their broad edge and lengthwise across the roadway, so as to form a close, firm pavement; the projections of the stones above an even surface are to be broken off by hand and hammer, and used, with other stones of proper size and shape, as wedges, to firmly wedge the stones of the base in proper position, so that the surface of the base will be parallel to the subgrade for the roadway and eight inches above it; the base is then to be thoroughly rolled with a steam-roller.

"SECT. 7.—*Macadam Surface.*—(*a*) Upon the telford base is to be laid the macadam surface, made as follows: Hard, durable broken stones, which will pass through a screen with 2¼-inch round holes, and will not pass through a screen with one-inch round holes, and are free from round or other ill-shaped or improper stones, are to be spread over the whole surface of the base, and thoroughly rolled and packed with a fifteen-ton steam road-roller of approved pattern, until the surface is one-half inch below the finished roadway; the spaces between these stones are then to be filled with fine screenings or binding-gravel applied in at least three layers; each layer thoroughly worked in by wetting and rolling as aforesaid before the next layer is applied, and during the operation the surface is to be brought, with the broken stone, to the grade and shape of the finished roadway, and smooth, free from waves or other irregularities; only the teaming necessary for distributing the screenings, and for rolling and wetting, is to be

allowed over the broken stone after it is spread on the base, and no teaming is to be allowed over the finished surface for at least three days after it is finished."

Extract from Brooklyn Specifications.

"(4) *Macadam Pavement.*—On the foundation for the macadam pavement prepared as heretofore described and after thorough rolling with a ten-ton steam-roller, there shall be spread a layer of trap-rock or limestone of such size that all of it will pass through a circular revolving screen having holes three inches in diameter and be retained by a similar screen with holes two inches in diameter.

"If limestone be used it shall be tough, hard, and uniform in color, and must not contain more than thirty per cent of lime. Trap-rock used in the lower or finishing course must be of uniform quality, free from sap, seams, and other imperfections. It shall be tough and not too brittle, and approximately cubical in form. Any lot of stone containing a noticeable proportion of stones whose length is more than twice their breadth will be rejected.

"This course shall be of such depth as will provide a thickness of four inches when consolidated. It shall then be rolled with a steam-roller weighing not less than ten tons, beginning at the sides and rolling towards the centre, until the stone is entirely compacted and does not move under the roller.

"After this rolling a second course of trap-rock and of such size that all of it will pass through a circular revolving screen having holes two inches in diameter and be retained by a similar screen having holes three-quarters of an inch in diameter shall be spread upon the roadway to such depth as will give a thickness of four inches after thorough rolling, and the surface shall conform exactly with the section shown on the profile plan. During the rolling of this course screenings of trap-rock and selected coarse sand or gravel shall be spread upon the stone in small quantities and washed in with a sprinkler. The trap-rock screenings shall be free from dirt and other foreign matter, and shall vary in size from one-half inch to dust, and about twenty per cent must

be what is known as trap-rock dust or flour. The sand must be coarse and only of such quality as may be approved by the Commissioner of Highways. Samples of this sand must be submitted to and approved by the said Commissioner before it can be used.

"Not less than six parts of the trap-rock screenings to four parts of the sand shall be used as a binding and filling material. The screenings and sand shall be placed upon the roadway only in such quantities as will fill the interstices, but leave no loose material upon the surface. Should an excess of fine material at any time be placed upon the roadway, it shall be swept off by hand-brooms before the work will be allowed to proceed. The rolling of this course shall be continued until the roadway is perfectly solid and compact.

"A finishing course consisting of trap-rock screenings and selected sand in the proportions above described shall then be spread over the roadway so that it completely covers the surface. This course shall be rolled and sprinkled simultaneously until it is brought to proper form and grade and is so hardened and bound that it will not pick up under travel."

Quantity of Material.

The amount of stone to be used in a macadam pavement will depend upon the amount of rolling and consolidation that is given to it. It is generally conceded by the best authorities that ordinary broken stone as used upon the street contains about 45 per cent voids. If we assume that the voids are compacted under the roller to 20 per cent and then filled with binder, the shrinkage caused by the rolling will be the same as the reduction of voids, or 25 per cent. Consequently it will require 10⅔ inches of loose stone spread upon the road to make a thickness of 8 inches when consolidated, and about 2 inches of binder will be required to fill the voids.

As a matter of fact, however, the voids are probably not absolutely filled by the binder, as the stone must wear into the base to a certain extent, so that with the above amount of 2 inches sufficient will be left to cover the surface of the road. When the road is finished to an absolute and arbitrary grade, any soft place

of the roadbed is liable to increase the amount of stone required, as any loss in the foundation must be made good at the surface.

To construct 18,400 square yards of macadam previously re-referred to under "Rolling" required 5400 yards of broken stone and 900 cubic yards of trap-rock screenings. This would give an area of 3.4 square yards of finished surface to 1 cubic yard of loose stone, and $\frac{1}{6}$ of the amount for binder. This piece of work was conscientiously and carefully done, and these amounts can be considered a fair average of what would be required on similar work.

In a discussion on road-making before the American Society of Civil Engineers, previously referred to, Mr. W. C. Foster in speaking on this point said that in some road-construction carried on under his direction the thickness of the loose stone was from 5½ to 6 inches on 4-inch work, and from 7¼ to 7½ inches on 6-inch work, and adds that the thicknesses were calculated from the actual car measurements and the number of yards laid. These results vary a little from that already given, but the difference is probably no more than would generally occur on roads laid on an earth base.

Cost of Construction.

The cost of building a macadam pavement is governed by so many different conditions that the cost in one place cannot be considered as a criterion for that in another, as the variations are quite great when apparently the conditions are the same.

On the assumption that the roadbed and base have already been prepared, the cost of a macadam pavement has been estimated as what might be expected under ordinary conditions, and correctio s can easily be made for any variations that may occur:

240 cubic yards of stone at $1.50 per yard	$360.00
40 cubic yards of binding material at $1.50	60.00
1 foreman at $5	5.00
10 laborers at $2.00 per day	20.00
2 rollers at $10 per day	20.00
Sprinkling	10.00
Total	$475.00

Assuming that one cubic yard of loose stone will lay 3½ square yards of pavement 8 inches thick, and that one roller will complete 420 square yards per day, the above material and organization will lay 840 square yards per day at a cost of 57 cents per yard, or making as the itemized cost per yard:

	Cents.
Stone	43
Binder	7
Labor	3
Sprinkling	1½
Rolling	2½
Total	57

Maintenance.

Probably the macadam streets of London have cost more for maintenance on account of their heavy traffic than those of other cities. It is said that in 1884 Parliament Street cost 70 cents, Whitehall Street 71 cents, and Victoria Street 50 cents per square yard for maintenance only.

Paris in 1893 expended 44 cents per square yard for maintenance of her macadam streets.

Maintenance of the macadam streets of Glasgow, Scotland, in 1896 and 1897 cost about 12 cents per yard. The cost of the Massachusetts roads for maintenance, according to the report of 1898, was about $108 per mile, including general repairs to the roads, such as washouts, etc., exclusive of the macadam roadway.

The cost in France in 1876 for the national highways was $165 per mile.

The following figures give the prices per square yard for maintenance of macadam roads in different cities and countries of Europe.

	Cents.
Liège, Belgium	1¼
Marseilles averaged	6½
Heavy-traffic streets	33
Dresden	3¾
Edinburgh	6
Tuscany	3 to 4
Spain	3
Switzerland	3

Resurfacing macadam streets in Rochester, N. Y., cost 7 cents per square yard in 1898.

Sprinkling.

The proper maintenance of macadam roads or paved streets involves systematic sprinkling. This serves a double purpose. It prevents the material from blowing away whenever small parts of it are loosened. The loose material on a street when sprinkled serves as a cushion for the wheels of the vehicles, and thus prevents to a great extent the direct action on the stone, thereby saving a large amount of wear. It also prevents the surface from picking up or ravelling under traffic in the dry season and so prevents abnormal wear. It is generally conceded by engineers that judicious sprinkling on a macadam road will more than pay for itself in the increased life it gives to the road, without taking into consideration the prevention of dust. Sprinkling, however, should be done with care and intelligence. It should be done often rather than have a large amount of water applied at one time, the object being to keep the loose material on top damp rather than wet, so as to prevent the formation of mud, or washing of the material into the gutter if the water is applied in large quantities.

Probably no more pavements such as those known as water-bound macadam will be laid in city streets. The increased use of the automobile during the last 10 years has changed all ideas of improving such pavements. If they are used at all it is almost always in connection with some bituminous material, either upon the surface or incorporated with the stone. If it be necessary to maintain a cheap pavement where macadam now exists it should be done in a manner somewhat similar to the methods described in the chapter on asphalt pavements, except that minor repairs will probably be made for some time in a less elaborate way.

It has been the practice, however, on the old macadam roads during the last few years to sprinkle the roads with liquid bitumen in order to lay the dust. Many different kinds of oil have been used, but with a heavy asphaltic oil it is possible, after a few applications, to produce a surface which is very similar to that

of an asphalt pavement and which will give very good service under moderate traffic. Some surprisingly good results have been obtained in this way.

The cost of oil treatment depends upon the character of the oil and how frequently it is applied. In the Borough of Brooklyn in 1911 631,854 gallons of oil were used in sprinkling macadam roads and unpaved streets. Some were sprinkled once, others twice, and some even three times. Reducing them, however, to a basis of one sprinkling the area treated amounted to 2,248,632 square yards. The cost of this work itemized was as follows:

Labor, including supervision and fixed charges	$3,443.56
Teams and sprinklers	4,087.99
Material	27,451.86
Total	$34,983.41

—or $1\frac{1}{2}$ cents per square yard.

The price paid for the oil was 5.95 cents per gallon for tar road oil and 3.58 cents per gallon for asphaltic road oil. The amount used averaged 1 gallon of oil for 3.6 yards of roadway.

CHAPTER XII.

CONCRETE PAVEMENTS.

CONCRETE pavements were probably first used in Bellefontaine, O. They were first tried there in 1884, and the streets so paved were in a fair condition after fifteen years of service. The city engineer in writing of them at that time said:

"The greatest objection is that they are slippery. Very few people here now advocate their construction, brick and asphalt having the preference."

In a letter dated March 8, 1912, the city engineer of Bellefontaine says:

"The concrete pavements laid in this city about 20 years ago are in very good condition, except that ruts have worn along the joints, which are parallel to the line of traffic. These have been repaired from time to time and at present the streets are in very good condition. This is a fault of construction entirely and could have been eliminated entirely. The cost of maintenance has been very small and has all been in repairing the above fault."

These pavements were laid on a 4-inch base formed of one part of the best Portland cement and four parts of gravel and sand about equally mixed. This was made into a concrete and thoroughly tamped on the street. Upon this, and before it was set, was spread the top course 2 inches thick, composed of one part of cement as above and one part of sand and gravel sifted to the size of a pea, a very thin layer of neat cement mortar being rubbed into the concrete to insure a good bond between the two layers.

Both layers were separated into blocks 5 feet square and the surface grooved into 4-inch squares, these grooves being V-shaped and $\frac{3}{16}$ inch deep and 1 inch wide.

When completed the entire surface was covered with 2 inches of wet sand and kept in that condition for 1 week.

During the past 8 or 10 years quite a large amount of concrete pavements has been laid. While in the main, of course, they must be very similar, still they vary in a number of respects. Two or three of these pavements have been patented and have been used to a considerable extent.

Granitoid Pavement.

This is one of the patented methods, and it can be described no better than by quoting the specifications as presented to the American Society of Municipal Improvements, it being assumed in all descriptions of concrete pavements that the cement used shall be Portland cement of the best quality and subject to all standard tests.

"*Mixing and Laying Concrete.*—The pavement shall consist of 5¼ inches of base and surface blocking 1¾ inches thick, making the total 7 inches, exclusive of foundation. After the subgrade and foundation have been prepared, as specified, there shall be deposited concrete composed of one part of Portland cement, three parts of sand and four parts of crushed stone, these materials to comply with the requirements above noted and shall be mixed by a machine suitable for the purpose, to be approved by the engineer. It shall be mixed at least six times before being removed from the mixer. The concrete shall be thoroughly tamped in place and shall be 5¼ inches thick at all points. After having been compacted it shall be laid in sections with expansion joints, all as per the Blome Company's patents, and shall follow the slopes of the finished pavement, so that the surface blocking shall be uniformly of the same thickness at all points.

"*Surfacing.*—After the concrete base has been placed, and before it has begun to set, there shall be immediately deposited thereon the Granitoid blocking, which shall be 1¾ inches thick. It will contain one part of Portland cement and one and one-half parts of clean monument crushed granite or trap rock. This granite shall be screened, with all dust removed therefrom, utilizing the following composition of this material: 50 per cent of granite to be what is known as ¼-inch size, 30 per cent of the ⅛-inch size, and 20 per cent of the $\frac{1}{10}$-inch size. This proportion

of sizes is essential and must be absolutely accurate, as in this lies one of the essential requirements to produce proper results; this material to be mixed with the cement thoroughly, and, after being wetted to a proper consistency and deposited on the concrete, shall be worked into brick shapes approximately 4½ by 9 inches, with rectangular surfaces similar to paving blocks. This will be done by special methods and utilizing the grooving apparatus as employed under the Blome Company's patents.

" *Expansion Joints.*—Expansion joints must be provided across the pavement at distances not exceeding 75 feet apart, and longitudinally continuously along the curb or gutter. These expansion joints shall extend through the blocking and concrete and shall be filled with a composition especially prepared for the purpose."

Hassam Pavement.

The following description and the claims for this pavement are taken from the trade circular recently issued by the company:

" *Process of Construction.*—Its method of construction consists of placing a layer of hard, tough broken rock, free from fine rock, dirt and dust, on a carefully prepared and rolled sub-grade. This layer of rock is made uniform in depth and of sufficient thickness to give a full 6 inches after being thoroughly compacted by rolling with a steam roller.

" The voids in the rock are then completely filled with 'grout,' which consists of one part Portland cement to two parts sand, mixed with sufficient water to make the grout flow freely into the voids of the rock, or about the consistency of thick cream. This grout is mixed thoroughly and continuously in specially constructed Hassam Grout Mixers, from which it flows by gravity through 4-inch metal conductors and is distributed directly onto the street. It percolates rapidly and freely into the rock and no one who has seen the operation can doubt for a moment that the rock voids are absolutely filled by this grout.

" Upon the surface thus prepared, a very thin layer of pea-sized broken rock is uniformly spread. The steam roller is again brought into service immediately after (almost simultaneously with) this grouting process and the grouted pavement is

carefully rolled and ' ironed ' out. This second rolling practically ' drives ' the grout into the interstices of the rock and has somewhat the same action that ' clamping ' has when two boards are glued together by a cabinet maker. The surface of the pavement is then broomed, which process removes the surplus water and gives the finishing touches to the appearance of the street.

" The unique methods peculiar to the construction of the Hassam Pavement render it many advantages, not the least among which is great durability. The use of the heavy roller on the rock before it is grouted, as well as afterward on the rock and mortar combined, give the Hassam ' compressed concrete ' a compressive strength many times that of concrete mixed in the old-fashioned manner; while the use of the very rich grout of cement and sand gives an unusually high tensile strength which is still further increased by the interlocking of the broken rock brought about by the thorough rolling. The result of the Hassam method of construction is the strongest and densest form of concrete known to-day which is applicable to practical uses.

" Its very density and imperviousness prevent the absorption of injurious foreign liquids and gases and insure sanitariness and ease of cleaning.

" Hassam pavement has a remarkable range of advantageous uses. It is the most comfortable hard-surface pavement in existence. In the hot summer days it does not radiate an intense heat as do bituminous and asphaltic pavements. And it does not soften under the sun's rays, and become sticky and hard to pull over, but always maintains a surface over which it is easy to travel and to haul a vehicle. In the winter, the rains do not render Hassam pavement slippery. On the contrary both horses and automobiles can travel over it with absolute safety and maximum efficiency whether wet or dry. It fills the requirements of both heavy and light traffic."

Dolarway Pavement.

This pavement was first used at Ann Arbor, Mich., in 1909, when 1883 square yards were laid, followed by 18,000 yards in 1910 and 64,000 in 1911 and in the spring of 1912 there were

petitions on file for 140,000 additional square yards. This pavement is practically a concrete pavement covered with a bituminous material. The requirements for the concrete at Ann Arbor are somewhat unique, as quoted herewith:

"One standard sack of cement shall be used for each square yard of pavement, and upon the completion of the pavement, if it shall be shown that less cement has been used than specified, the value thereof shall be deducted from any money due the contractor, and the contractor shall furnish to the Board of Public Works a sworn statement of the total quantity of cement used. Within 30 minutes after the concrete is placed it shall be struck off with a templet approved by the engineer until flush with the running boards, and as soon thereafter as practicable be trowelled to a true surface and be broomed as directed. An expansion joint 1 inch wide shall be left at each curb, and an expansion joint about ½ inch wide shall be left every 25 feet transversely of the street."

After the concrete has become thoroughly set and dry a thin coating of Dolarway bitumen, about ½ gallon per square yard, is applied at a temperature of about 200° F., and before the bitumen applied has become hard there is spread over the entire surface a uniform layer of torpedo sand, the transverse joints being filled with the bitumen and sand flush with the surface of the pavement. The thickness of the bitumen and sand ranges from ¼ to ⅜ of an inch. It is claimed for this pavement that the concrete serves really as the pavement and that the surface coating of bitumen and sand protects the concrete from wear, so preventing the formation of dust and giving practically an asphalt pavement so far as use is concerned.

The cost of the pavement varies, of course, according to localities and the cost of materials, but it is stated that if there be added to the cost of concrete 25 to 35 cents per square yard, the same being, the cost of the bitumen and the royalty charged by the company, the total cost of the pavement can be obtained. It is stated also that the pavement can be resurfaced at an approximate cost of 10 cents per square yard.

The Association for Standardizing Paving Specifications, at its annual meeting in New Orleans in January, 1912, also

adopted specifications for concrete pavements. These specifications are for a single-course pavement, and provide that in preparing the concrete the cement and aggregates shall be measured separately and then mixed in such proportions that the resulting concrete shall contain fine aggregate amounting to one-half the volume of the coarse aggregate and that 5 cubic feet of concrete in place shall contain 94 pounds of cement; it having already stipulated in the sidewalk specifications that the fine aggregate shall consist of any material of siliceous, granitic or igneous origin, free from mica in excess of 5 per cent and other impurities, and shall be of graded sizes ranging from ¼ inch down to that which shall be retained on a No. 100 standard sieve, not more than 20 per cent of which will pass a No. 50 standard sieve for the base; and from ¼ inch down to that which will be retained on a No. 80 standard sieve, not more than 20 per cent of which shall pass a No. 50 standard sieve for the top or wearing surface; and that the coarse aggregate should be sand, gravel, broken stone or slag having a specific gravity not less than 2.6, and that it should be free from all foreign matter, uniformly graded and of sizes that shall pass a ½-inch screen and be retained on a ¼-inch screen.

The specifications also provided that the pavement shall be finished by thorough hand tamping until the mortar flushes freely to the surface, then lightly tamped with a templet made of 2-inch plank, shaped to conform to the curvature of the surface of the finished pavement and having a length of not less than one-half the width of the roadway to give a uniform surface with slight markings made transverse to the street. If it is proposed to complete the pavement with a bituminous wearing surface, the specifications state that the pavement shall be lightly broomed at right angles to the curbing immediately after the tamping above specified has been completed.

The requirements for expansion joints provided that they shall be placed at right angles to the curb line at intervals of 50 feet, the joints to be not less than 1 inch wide and filled with creosoted soft wood timber with the grain vertical and extending the full depth of the pavement. That when it was proposed to complete the pavement with a bituminous wearing surface the

expansion joints should be filled with a suitable elastic waterproof filler that would not become soft and run out in hot weather nor hard or brittle and chip out in cold weather; all expansion joints to be filled flush with the surface of the concrete before the bituminous wearing surface should be placed.

It should be noted that the novelty in the foregoing specifications is that it requires the expansion joint to be filled with creosoted wood. It was stated at the convention by the City Engineer of Memphis that 50 feet apart was near enough for the joints, and upon being asked what the condition of the pavement was around the joints he replied that there was hardly any evidence of a joint, that the wood seemed to hold the edge perfectly and prevent trouble.

The Universal Portland Cement Co. has put out a pamphlet giving very complete and full details regarding concrete pavements in this country. It is there stated that for several years in Windsor, Ontario, concrete pavements have been laid at a cost to the city ranging from 99 cents to $1.15 per square yard.

The pavement consists of a 4-inch hand-mixed concrete base of 1:3:7 mix, Portland cement, sand, and ¼-inch to 3-inch crushed limestone. Two different wearing surfaces were used. One some streets the 4-inch concrete base was covered with 2 inches of 1:2:4 gravel concrete, and on the other streets a layer of 1:2:4 gravel concrete 1½ inches thick was covered with ½ an inch of 1:2 sand mortar. The cost of the material and labor is given as follows:

Portland cement per barrel	$2.05
River sand per cubic yard	1.15
Screened gravel per cubic yard	1.25
Crushed limestone per ton	1.15
Common labor	1.75 to $2.00

It is also stated that at $1.15 per square yard the contractor made a fair profit, but that at 99 cents the profit was questionable.

The specifications given in the pamphlet for concrete pavements are as follows:

"*Cement.*—Only Portland cement shall be used which shall conform in every respect to the Standard Specifications for

Portland cement adopted by the American Society for Testing Materials, November 14, 1904, with subsequent amendments.

" *Sand.*—The sand shall be clean, coarse and of good quality, free from all foreign matter, except clay which will be permitted if the quantity does not exceed five (5) per cent and provided it does not occur as a coating on the sand grains. The sand shall pass a No. 4 mesh.

"Not more than 40 per cent shall be retained on a No. 10 mesh.
"Or 35 per cent pass a No. 10 and be retained on a No. 20.
"Or 35 per cent pass a No. 20 and be retained on a No. 30.
"Or 35 per cent pass a No. 30 and be retained on a No. 40.
"Or 35 per cent pass a No. 40 and be retained on a No. 50.
"Not more than 20 per cent shall pass a No. 50 mesh.
"Or 70 per cent pass a No. 10 and be retained on a No. 40.
"Or 70 per cent pass a No. 20 and be retained on a No. 50.

" *Screenings.*—The screenings, all of which shall pass a No. 4 mesh, shall be crushed from clean, sound, hard, durable rock and shall be clean, dry, well graded and free from excessive dust, which shall not occur as a coating on the particles of stone.

" *Coarse Aggregates.*—The coarse aggregates shall be so broken, or screened as to be retained on a one-quarter ($\frac{1}{4}$) inch mesh, and pass in any direction through a one and one-quarter ($1\frac{1}{4}$) inch mesh.

" The crushed stone shall be from clean, hard, sound, durable rock; the gravel of good quality, and the crushed slag from hard, dense, blast furnace slag.

" *Proportioning Concrete.*—All materials, except the cement, shall be measured in suitable bottomless measuring boxes, or by wheelbarrows of a measured capacity, after the surface has been struck with a straightedge or templet. A sack of cement (94 pounds) shall be considered to have a volume of one (1) cubic foot.

" *Mixing.*—The concrete may be either hand or machine mixed.

" When the conditions will permit, a mixing machine of a type which will insure the uniform proportioning of materials throughout the mass, should be used.

"Hand-mixed concrete shall be mixed on a water-tight wood or metal platform, either with short-handled shovels or hoes.

"When shovels are used in mixing the mixing board may be either of metal or of wood. The required amount of sand shall be spread over the surface of the board in a thin layer of uniform thickness. On top of the sand the required amount of cement shall be spread, and the sand and cement mixed dry to a uniform color, and again spread over the surface of the mixing board. The required amount of aggregate shall then be added and the mass turned dry at least twice. The required amount of water shall be added and the mass mixed until a homogeneous concrete is obtained in which all particles of aggregate are thoroughly coated with mortar.

"When the mixing is done with a hoe a suitable metal mixing board shall be used. The sand shall be spread in a layer of uniform thickness over one-half the area of the board. The cement shall be spread evenly over the sand, and the mass mixed dry by hoeing to the opposite side of the board, and evenly spread over the surface of this half of the board. The required amount of water to make a thin mortar shall than be added, and the mortar hoed back to its original position. The required amount of aggregate shall be added and the mass hoed from one side of the board to the other and back again, and immediately shovelled into place from the board, or into wheelbarrows.

"Retempering, that is, remixing with additional water, mortar or concrete that has partially hardened will not be permitted.

"*Pavement Proper. Two-coat Work.*—The pavement proper shall consist of a six (6) inch concrete base and a wearing surface of at least one and one-half (1½) inches for residence districts and of at least two (2) inches for business districts.

"*Concrete Base.*—Upon a properly prepared sub-grade or sub-base as hereinbefore specified shall be deposited six (6) inches of well mixed, properly proportioned concrete.

"This concrete shall be composed of Portland cement, sand or stone screenings, and a coarse aggregate, either crushed stone or slag, or screened gravel.

"The concrete for the base shall be so proportioned that

the cement shall overfill the voids in the sand or screenings by at least five (5) per cent, and the mortar shall overfill the voids in the aggregate by at least ten (10) per cent.

"When the voids are not determined the concrete shall be mixed one (1) sack of cement to three (3) cubic feet of sand or screenings, and five (5) cubic feet of coarse aggregate.

"The concrete base shall be mixed as wet as is practicable, but not so wet that it will creep toward the curb or sag out of place when deposited and lightly tamped.

"The concrete base shall be deposited in strips extending across the full width of the area paved, and shall be deposited as soon after mixing as is practicable, but in no case shall more than thirty (30) minutes elapse between the mixing and depositing of the concrete base.

"The concrete shall be well tamped to a surface, the thickness of the wearing surface below the finished surface of the pavement, with hand tampers, approximately eight (8) inches in diameter and weighing not less than eighteen (18) pounds.

"On streets where the curbs or combination curb and gutter are in, the pavement shall be separated from same by a three-eighths ($\frac{3}{8}$) inch expansion joint.

"A three-eighths ($\frac{3}{8}$) inch expansion joint shall be placed across the street at least every twenty-five (25) feet running from curb to curb perpendicular to the axis of the street.

"*Wearing Surface. Cement Mortar.*—The concrete base before it begins to harden shall be covered with a top coat or wearing surface of a thickness hereinbefore specified, composed of one (1) part cement to one and one-half ($1\frac{1}{2}$) parts suitable stone screenings or sand.

"The men laying the wearing surface shall follow closely behind those laying the concrete base, and in no case shall more than fifty (50) minutes elapse between the mixing of the concrete base and the covering of same with the wearing surface.

"The wearing surface shall be finished with a wood float and roughened by brushing with a street broom as directed by the engineer in charge.

"*Pavement Proper. Single-coat Work.*—Upon a properly prepared sub-grade or sub-base as hereinbefore specified, shall

be deposited six (6) inches of well-mixed, properly proportioned concrete.

"This concrete shall be composed of a coarse aggregate and a Portland cement mortar mixed one (1) part cement to one and one-half (1½) parts suitable sand or stone screenings.

"The concrete shall be so proportioned that the hereinbefore specified mortar shall overfill the voids in the coarse aggregate by at least five (5) per cent.

"Where the voids in the coarse aggregate are not determined the concrete shall be mixed one (1) sack of cement to one and one-half (1½) cubic feet of sand or screenings and three (3) cubic feet of coarse aggregate.

"The concrete shall be mixed and deposited and expansion joints placed as specified for *concrete base—two-coat work.*

"The concrete shall be well tamped until the mortar flushes to the surface, and the surface shall be finished as specified for *wearing surface—cement mortar.*

"*Wearing Surface. Bitumen and Sand.*—A wearing surface or bitumen and sand may be placed upon a two-coat or a single-coat concrete pavement constructed as specified.

"After the concrete has hardened the dry, clean surface of the pavement shall be covered with hot bitumen of a quality to be approved by the engineer.

"The hot bitumen shall be sprinkled over the surfa e of the concrete from suitable hand sprinkling cans or from a sprinkler wagon designed for the purpose having a firebox under the tank to heat the bitumen.

"Between one-third (⅓) and one-half (½) gallon of bitumen shall be applied per square yard of pavement, which shall be immediately evenly distributed over the surface of the concrete by brushing with a suitable street broom and covered with suitable clean, coarse sand or stone screenings.

"Approximately one (1) cubic yard of sand or stone screenings shall be used for each two hundred and twenty-five (225) square yards of pavement, which shall be evenly spread over the surface.

"Before applying a wearing surface of bitumen and sand all expansion joints in the pavement shall be filled as hereinafter specified.

"*Expansion Joints.*—All expansion joints shall extend through the entire thickness of the pavement proper and the upper edges shall be neatly rounded to a radius of one-half (½) inch to prevent chipping and spalling.

"The joints shall be filled with a suitable elastic waterproof filler that will not become soft and run out in hot weather, or hard and brittle and chip out in cold weather.

"*Protection.*—When completed the concrete shall be kept well sprinkled with water for a period of at least three days, and the pavement shall not be thrown open to traffic until the engineer so directs. Under the most favorable conditions for hardening, in hot dry weather the pavement shall be protected from traffic for at least seven days, and in cold damp weather for an additional length of time, to be determined by the engineer."

It will be noticed that while the proportions used in the different methods of making concrete pavements vary somewhat, the principal difference is in whether the pavement shall be laid in one thickness or whether it shall be made up of a base and a wearing surface; also, what shall be the proper size of the different aggregates. Where two-coat work is used the wearing surface should be laid almost immediately after the lower course, not more than an hour intervening in any event, so that the upper surface shall form a perfect bond with the lower.

Engineers as a rule specify that the top course shall be made of comparatively fine crushed stone, and some even specify sand. Mr. S. Whinery, Consulting Engineer of New York City, however, in an article in the *Municipal Journal* of April 4, 1912, recommends a foundation course 4 inches thick, made up of 1 : 3 : 7 concrete, and a top course 2 inches thick, using as hard and tough a stone as possible. He says that if practicable all fragments over 1½ inches and under ½ inch in size should be screened out, and, while the ratio for the surface course ought to be determined for each particular material used, as is done in the high class concrete, a typical composition that should give good results is 1 : 2 : 4. He estimates the typical cost for such a pavement as the above at $75^1/_{10}$ cents, and that for a single-course pavement mixed in the ratio of 1 : 2½ : 5 at $77^3/_{10}$ cents.

Engineering Contracting of April 3, 1912, gives the cost of concrete pavements in different places as follows:

Reinforced concrete pavement, Fon du Lac, Wis.; pavement 6½ in. thick, 5 in. base, mix 1 : 2½ : 5; 1½ in. top, 1 : 1 : 1 granite...... $1.25
Sheboygan Falls, Wis.; pavement 8½ in. thick at center, 6½ in. at curb. 1.28

One-course concrete, the price in eight cities ranged from 90 cents to $1.70, the thickness varying from 5 inches to 7 inches.

Two-course concrete was as follows:

Town.	Price.	Quantity. Square Yards.	Thickness of Base, Inches.	Proportions.	Thickness of Top. Inches.	Proportion.
Alpena, Mich........	$1.30	13,000	6	1 : 6	2	
Billings, Mont.......	2.25	2,000	6	1 : 6	1½	1 : 2
Davenport, Iowa....	1.23	13,208	5	1 : 3 : 5	2	1 : 2
Edwardsville, Ill.....	1.40	8,950	5	1 : 3 : 5	2	1 : 1 : 1
Fort Dodge, Iowa...	1.60	7,900	5	1 : 3 : 5	2	1 : 1 : 1
Grand Junction, Colo.	2.20	18,000	5	1 : 3 : 6	2	

The following is the cost of constructing a concrete road in Ada County, Idaho (8-hour day).*

3 men wheeling 2 men shoveling gravel at mixer } 5 at $2.75.........	$13.75
2 men wheeling sand at $2.75......................	5.50
1 man wheeling cement, 1 loading cement, 2 at $2.75..	5.50
1 mixer man on loading and tending water..........	2.75
1 engineer (sub-foreman) and delivery operator.......	3.00
3 men setting forms at $2.75......................	8.25
1 sub-foreman..................................	3.00
1 superintendent with mount.....................	5.00
Engineering and field supervision..................	25.00
1 water team and man...........................	7.25
.005 depreciation on equipment...................	10.00
1 timekeeper....................................	3.00
MATERIALS.	
1200 square yards crushed gravel and sand at .07.....	$84.00
91 barrels Red Devil Portland cement at $2.60.......	236.60
5 gallons gasoline for mixer at 23 cts. (oil 15 cts.).....	1.30
	$413.90

600 square yards concrete 7 in. thick per day.
Cost per square yard, 69 cts., 116 cubic yards.
Concrete mixed 1 : 2½ : 4.

A Koehring Paving Mixer was used for this work.

* "Good Roads," March 2, 1912.

STANDARD SPECIFICATIONS FOR CEMENT

Adopted August 16, 1909, by the American Society for Testing Materials.

General Observations.—1. These remarks have been prepared with a view of pointing out the pertinent features of the various requirements and the precautions to be observed in the interpretation of the results of the tests.

2. The Committee would suggest that the acceptance or rejection under these specifications be based on tests made by an experienced person having the proper means for making the tests.

Specific Gravity.—3. Specific gravity is useful in detecting adulteration. The results of tests of specific gravity are not necessarily conclusive as an indication of the quality of a cement, but when in combination with the results of other tests may afford valuable indications.

Fineness.—4. The sieves should be kept thoroughly dry.

Time of Setting.—5. Great care should be exercised to maintain the test pieces under as uniform conditions as possible. A sudden change or wide range of temperature in the room in which the tests are made, a very dry or humid atmosphere, and other irregularities vitally affect the rate of setting.

Constancy of volume.—6. The tests for constancy of volume are divided into two classes, the first normal, the second accelerated. The latter should be regarded as a precautionary test only, and not infallible. So many conditions enter into the making and interpreting of it that it should be used with extreme care.

7. In making the pats the greatest care should be exercised to avoid initial strains due to molding or to too rapid drying-out during the first 24 hours. The pats should be preserved under the most uniform conditions possible, and rapid changes of temperature should be avoided.

8. The failure to meet the requirements of the accelerated tests need not be sufficient cause for rejection. The cement may, however, be held for 28 days, and a retest made at the end of that period, using a new sample. Failure to meet the require-

ments at this time should be considered sufficient cause for rejection, although in the present state of our knowledge it cannot be said that such failure necessarily indicates unsoundness, nor can the cement be considered entirely satisfactory simply because it passes the tests.

SPECIFICATIONS

General Conditions.—1. All cement shall be inspected.

2. Cement may be inspected either at the place of manufacture or on the work.

3. In order to allow ample time for inspecting and testing, the cement should be stored in a suitable weather-tight building having the floor properly blocked or raised from the ground.

4. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment.

5. Every facility shall be provided by the contractor and a period of at least twelve days allowed for the inspection and necessary tests.

6. Cement shall be delivered in suitable packages with the brand and name of manufacturer plainly marked thereon.

7. A bag of cement shall contain 94 pounds of cement net. Each barrel of Portland cement shall contain 4 bags, and each barrel of natural cement shall contain 3 bags of the above net weight.

8. Cement failing to meet the 7-day requirements may be held awaiting the results of the 28-day tests before rejection.

9. All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, and amended January 20, 1904, and January 15, 1908, with all subsequent amendments thereto.

10. The acceptance or rejection shall be based on the following requirements:

NATURAL CEMENT

11. *Definition.*—This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous

limestone at a temperature only sufficient to drive off the carbonic acid gas.

Fineness.—12. It shall leave by weight a residue of not more than 10 per cent on the No. 100, and 30 per cent on the No. 200 sieve.

Time of Setting.—13. It shall not develop initial set in less than 10 minutes; and shall not develop hard set in less than 30 minutes, or in more than 3 hours.

Tensile Strength.—14. The minimum requirements for tensile strength for briquettes 1 square inch in cross-section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

Age.	Strength.
24 hours in moist air	75 lbs.
7 days (1 day in moist air, 6 days in water)	150 "
28 days (1 " " 27 days ")	250 "

ONE PART CEMENT, THREE PARTS STANDARD OTTAWA SAND.

7 days (1 day in moist air, 6 days in water)	50 lbs.
28 days (1 " " 27 " ")	125 "

Constancy of Volume.—15. Pats of neat cement about 3 inches in diameter, ½ inch thick at center, tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

(*a*) A pat is then kept in air at normal temperature.

(*b*) Another is kept in water maintained as near 70° F. as practicable.

16. These pats are observed at intervals for at least 28 days, and, to satisfactorily pass the tests, shall remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

Portland Cement

17. *Definition.*—This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination.

Specific Gravity.—18. The specific gravity of cement shall not be less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

Fineness.—19. It shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

Time of Setting.—20. It shall not develop initial set in less than 30 minutes; and must develop hard set in not less than 1 hour, nor more than ten hours..

Tensile Strength.—21. The minimum requirements for tensile strength for briquettes 1 square inch in cross-section shall be as follows, and the cement shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

Age.	Strength.
24 hours in moist air	175 lbs.
7 days (1 day in moist air, 6 days in water)	500 "
28 days (1 " " 27 " ")	600 "

ONE PART CEMENT, THREE PARTS STANDARD OTTAWA SAND.

7 days (1 day in moist air, 6 days in water)	200 lbs.
28 days (1 " " 27 " ")	275 "

Constancy of Volume.—22. Pats of neat cement about 3 inches in diameter, ½ inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(*b*) Another pat is kept in water maintained as near 70° F. as practicable, and observed at intervals for at least 28 days

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 5 hours.

23. These pats, to satisfactorily pass the requirements, shall remain firm and hard, and show no signs of distortion, checking, cracking, or disintegrating.

Sulphuric Acid and Magnesia.—24. The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO).

METHODS FOR TESTING CEMENT.*

(Condensed for use in Specifications.)

1. *Sampling.*—Cement in barrels shall be sampled through a hole made in the head, or in one of the staves midway between the heads, by means of an auger or a sampling iron similar to that used by sugar inspectors; if in bags, the sample shall be taken from surface to center. Cement in bins shall be sampled in such a manner as to represent fairly the contents of the bin. The number of samples taken shall be as directed by the engineer, who will determine whether the samples shall be tested separately or mixed.

The samples shall be passed through a sieve having twenty meshes per linear inch, in order to break up lumps and remove foreign material.

2. *Chemical Analysis.*—The method to be followed shall be that proposed by the Committee on Uniformity in the Analysis of Materials for the Portland Cement Industry, reported in the *Journal* of the Society for Chemical Industry, Vol. 21, p. 12, 1902, and published in *Engineering News*, Vol. 50, p. 60, 1903, and in *Engineering Record*, Vol. 48, p. 49, 1903, and in addition thereto the following:

The insoluble residue shall be determined as follows: To a 1-gram sample of the cement shall be added 30 cubic centimeters of water and 10 cubic centimeters of concentrated hydrochloric acid, and then warmed until the effervesence ceases, and digested on a steam bath until dissolved. The residue is filtered, washed with hot water, and the filter paper and contents digested on the steam bath in a 5 per cent solution of sodium carbonate. This residue is filtered, washed with hot water, than with hot hydro-

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* Accompanying Final Report of Special Committee of the American Society of Civil Engineers on Uniform Tests of Cement, dated January 17, 1912. Page 126, Proceedings of said Society, February, 1912.

chloric acid, and finally with hot water, and then ignited at a red heat and weighed. The quantity so obtained is the insoluble residue.

3. *Specific Gravity.*—The determination of specific gravity shall be made with a standardized Le Chatelier apparatus. This

B

LE CHATELIER'S SPECIFIC GRAVITY APPARATUS.

Fig. 25.

consists of a flask (*D*), Fig. 25, of about 120 cubic centimeters capacity, the neck of which is about 20 centimeters long; in the middle of this neck is a bulb (*C*), above and below which are two marks (*F*) and (*E*); the volume between these two

marks is 20 cubic centimeters. The neck has a diameter of about 9 millimeters, and is graduated into tenths of cubic centimeters above the mark (*F*).

Benzine (62° Beaumé naphtha) or kerosene free from water shall be used in making the determination. The flask is filled with either of these liquids to the lower mark (*E*) and 64 grams of cement, cooled to the temperature of the liquid, is slowly introduced through the funnel (*B*), (the stem of which should be long enough to extend into the flask to the top of the bulb (*C*), taking care that the cement does not adhere to the sides of the flask, and that the funnel does not touch the liquid. After all the cement is introduced, the level of the liquid will rise to some division of the graduated neck; this reading, plus 20 cubic centimeters, is the volume displaced by 64 grams of the cement. The specific gravity is obtained from the formula,

$$\text{Specific gravity} = \frac{\text{Weight of cement, in grams}}{\text{Displaced volume, in cubic centimeters}}.$$

The flask, during the operation, is kept immersed in water in a jar (*A*), in order to avoid variations in the temperature of the liquid in the flask, which should not exceed $\frac{1}{2}°$ C. The results of repeated tests should agree within 0.01.

The determination of specific gravity shall be made on the cement as received; if it should fall below 3.10 ,a second determination shall be made after igniting the sample at a low red heat. The ignition shall be carried out in the following manner:

One-half gram of cement is heated in a weighed platinum crucible, with cover, for 5 minutes with a Bunsen burner (starting with a low flame and gradually increasing to its full height) and then heated for 15 minutes with a blast lamp; the difference between the weight after cooling and the original weight is the loss on ignition. The temperature should not exceed 900° C., and the ignition should preferably be made in a muffle.

4. *Fineness.*—The fineness shall be determined by weighing the residue retained on No. 100 and No. 200 sieves. The sieves shall be of brass wire, and shall conform to the following requirements:

No. of Sieve.	Diameter of Wire.	Meshes per Linear Inch.	
		Warp.	Woof.
100	0.0042 to 0.0048 in.	95 to 101	93 to 103
200	0.0021 to 0.0023 in.	192 to 203	190 to 205

The meshes in any smaller space, down to 0.25 inch, shall be proportional in number.

Fifty grams of cement, dried at a temperature of 100° C. (212° F.), shall be placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position, and moved forward and backward about 200 times per minute, at the same time striking the side gently, on the up stroke, against the palm of the other hand. The operation is continued until not more than 0.05 gram will pass through in one minute. The residue is weighed, then placed on the No. 100 sieve, and the operation repeated. The work may be expedited by placing in the sieve a few large steel shot, which should be removed before the final one minute of sieving. The sieves should be thoroughly dry and clean.

5. *Normal Consistency.*—The amount of water, expressed in percentage by weight of the dry cement, required to produce a paste * of the plasticity desired, termed "normal consistency," shall be determined with the Vicat apparatus:

This consists of a frame (*A*), Fig. 26, page 428, bearing a movable rod (*B*), weighing 300 grams, one end (*C*) being 1 centimeter in diameter for a distance of 6 centimeters, the other having a removable needle (*D*), 1 millimeter in diameter, 6 centimeters long. The rod is reversible, and can be held in any desired position by a screw (*E*), and has midway between the ends a mark (*F*) which moves under a scale (graduated to millimeters) attached to the frame (*A*). The paste is held in a conical, hard-

* The term "paste" is used in these specifications to designate a mixture of cement and water, and the word "mortar" to designate a mixture of cement, sand, and water.

rubber ring (*G*), 7 centimeters in diameter at the base, 4 centimeters high, resting on a glass plate (*H*) about 10 centimeters square.

In making the determination of normal consistency, the same quantity of cement as will be used subsequently for each batch in

H

VICAT APPARATUS

Fig. 26.

making the test pieces, but not less than 500 grams, together with a measured amount of water, is kneaded into a paste, as described in Section 9, and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained about 6 inches apart; the ball

resting in the palm of one hand is pressed into the larger end of the rubber ring held in the other hand, completely filling the ring with paste; the excess at the larger end is then removed by a single movement of the palm of the hand; the ring is then placed on its larger end on a glass plate and the excess paste at the smaller end is sliced off at the top of the ring by a single oblique stroke of a trowel held at a slight angle with the top of the ring. During these operations care must be taken not to compress the paste. The paste confined in the ring, resting on the plate, is placed under the rod, the larger end of which is carefully brought in contact with the surface of the paste; the scale is then read, and the rod quickly released.

The paste is of normal consistency when the cylinder settles to a point 10 millimeters below the original surface in ½ minute after being released. The apparatus must be free from all vibrations during the test.

Trial pastes are made with varying percentages of water until the normal consistency is attained.

Having determined the percentage of water required to produce a paste of a normal consistency, the percentage required for a mortar containing, by weight, one part of cement to three parts of standard Ottawa sand, shall be obtained from the following table, the amount being a percentage of the combined weight of the cement and sand.

PERCENTAGE OF WATER FOR STANDARD MORTARS.

Neat.	One Cement, Three Standard Ottawa Sand.	Neat.	One Cement, Three Standard Ottawa Sand.	Neat.	One Cement, Three Standard Ottawa Sand.
15	8.0	23	9.3	31	10.7
16	8.2	24	9.5	32	10.8
17	8.3	25	9.7	33	11.0
18	8.5	26	9.8	34	11.2
19	8.7	27	10.0	35	11.3
20	8.8	28	10.2	36	11.5
21	9.0	29	10.3	37	11.7
22	9.2	30	10.5	38	11.8

6. *Time of Setting.*—The time of setting shall be determined with the Vicat apparatus in the following manner:

A paste of normal consistency is moulded in the hard-rubber ring, as described in Section 5, and placed under the rod (*B*), the smaller end of which is then carefully brought in contact with the surface of the paste, and the rod quickly released.

The cement is considered to have acquired its initial set when the needle ceases to pass a point 5 millimeters above the glass plate; and the final set, when the needle does not sink visibly into the paste.

The test pieces must be kept in moist air during the test.

7. *Standard Sand.* The sand shall be natural sand from Ottawa, Ill., screened to pass a No. 20 sieve, and retained on a No 30 sieve.

The sieves shall be at least 8 inches in diameter, and the wire cloth shall be of brass wire and shall conform to the following requirements:

No. of Sieve.	Diameter of Wire.	Meshes per Linear Inch.	
		Warp.	Woof.
20	0.016 to 0.017 in.	19.5 to 20.5	19 to 21
30	0.011 to 0.012 in.	29.5 to 30.5	28.5 to 31.5

Sand which has passed the No. 20 sieve is standard when not more than 5 grams passes the No. 30 sieve in 1 minute of continuous sifting of a 500-gram sample.*

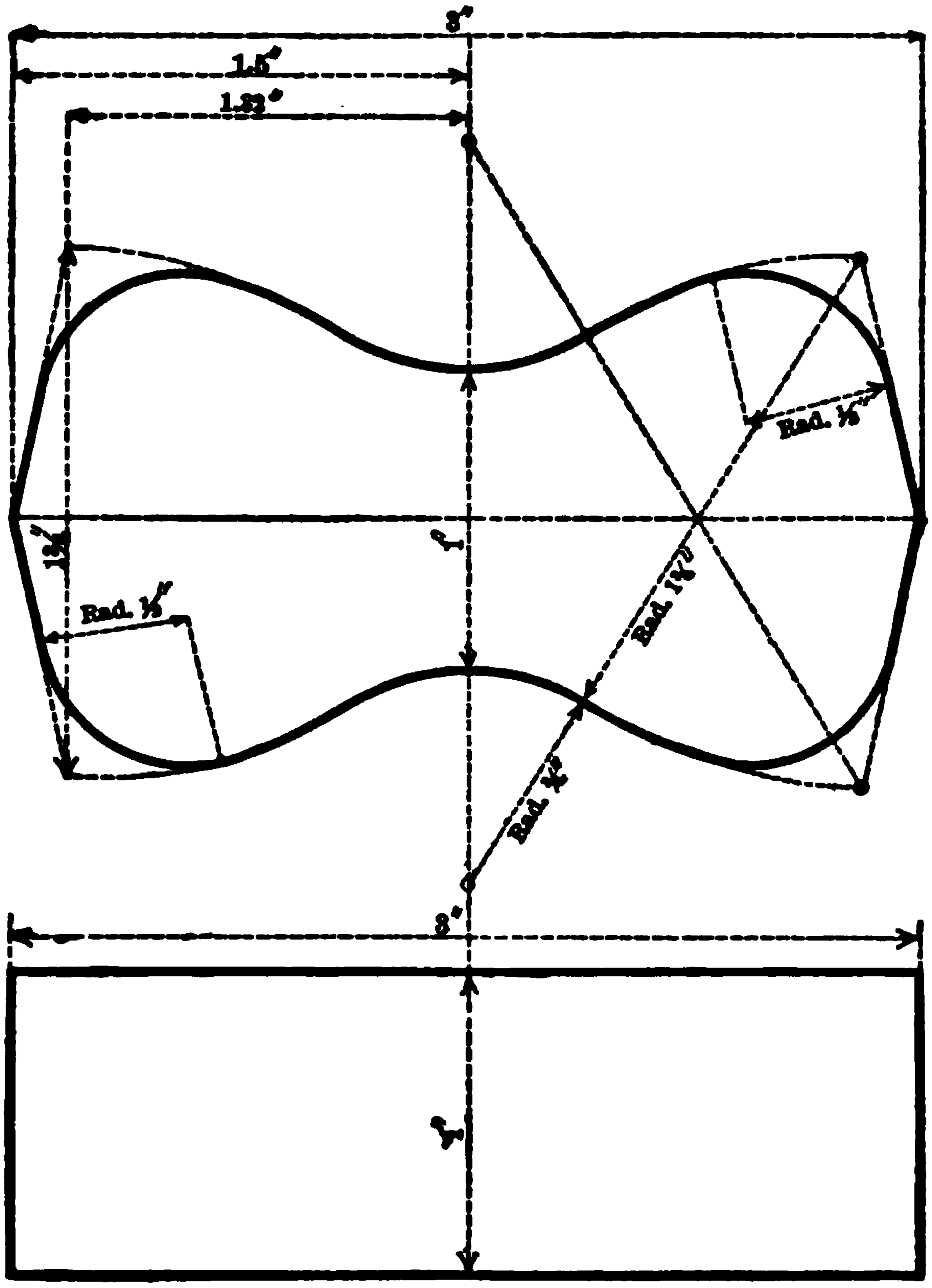
8. *Form of Test Pieces.*—For tensile tests the form of test pieces shown in Fig. 27 shall be used.

For compressive tests, 2-inch cubes shall be used.

9. *Mixing and Moulding.*—The material shall be weighed, placed on a non-absorbent surface, thoroughly mixed dry if sand be used, and a crater formed in the center into which the proper percentage of clean water shall be poured; the material on the

* This sand may now (1912) be obtained from the Ottawa Silica Co., at a cost of two cents per pound, f.o.b. cars, Ottawa, Ill.

outer edge shall be turned into the center by the aid of a trowel. As soon as the water has been absorbed, the operation of mixing



DETAILS FOR BRIQUETTE.
FIG. 27.

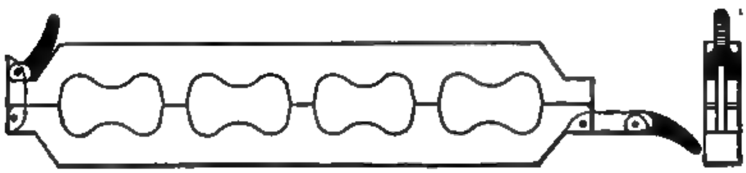
shall be completed by vigorously kneading with the hands for 1 minute.

Immediately after mixing, the paste or mortar shall be placed the mould (Figs. 28 and 29) with the hands, pressed in firmly with the fingers, and smoothed off with a trowel without ramming. The material shall be heaped above the mould, and, in smoothing off, the trowel shall be drawn over the mould in such a manner

as to exert a moderate pressure on the material; the mould shall then be turned over and the operation of heaping and smoothing off repeated.

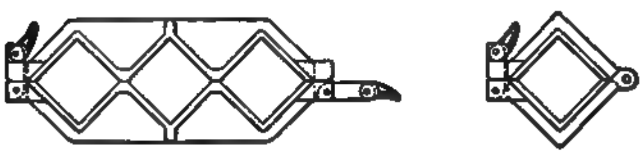
The temperature of the room and of the mixing water shall be maintained as nearly as practicable at 21° C. (70° F.).

10. *Storage of the Test Pieces.*—During the first 24 hours after moulding, the test pieces shall be stored in a moist closet This consists of a box of soapstone or slate, or of wood lined with metal, the interior surface being covered with felt or broad wick.



DETAILS FOR GANG MOULD.

FIG. 28.



MOULD FOR COMPRESSION TEST PIECES

FIG. 29.

ing kept wet, the bottom of the box being kept covered with water The interior of the box is provided with glass shelves on which to place the test pieces, the shelves being so arranged that they may be withdrawn readily.

Test pieces from any sample which vary more than 3 per cent in weight from the average, after removal from the moist closet. shall not be considered in determining strength.

After 24 hours in the moist closet, the pieces to be tested after longer periods shall be immersed in water in storage tanks or pans made of non-corrodible material.

The air and water in the moist closet and the water in the storage tanks shall be maintained, as nearly as practicable, at 21° C. (70° F.).

11. *Tests of Tensile Strength.*—The tests may be made with any standard machine.

The clip is shown in Fig. 30. It must be made accurately, the pins and rollers turned, and the rollers bored slightly larger

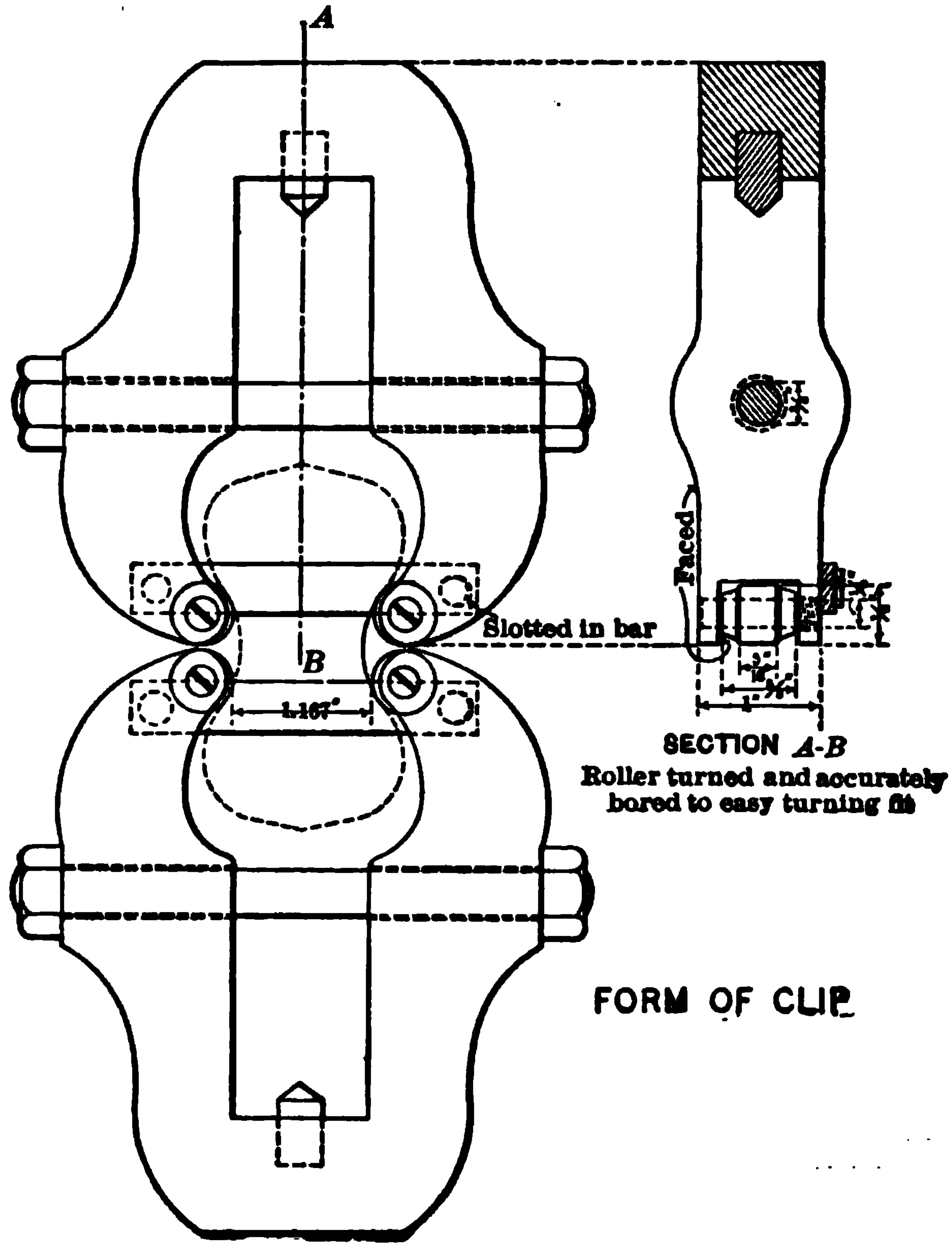


Fig. 30.

than the pins so as to turn easily. There should be a slight clearance at each end of the roller, and the pins should be kept properly lubricated and free from grit. The clips shall be used without cushioning at the points of contact.

The test pieces shall be broken as soon as they are removed from the water. The load shall be applied at the rate of 600 pounds per minute.

Test pieces which do not break within ½ inch of the center, or are otherwise manifestly faulty, shall be excluded in determining average results.

12. *Tests of Compressive Strength.*—The tests may be made with any machine provided with means for so applying the

Head of Testing Machine

BALL-BEARING BLOCK FOR TESTING MACHINE

FIG. 31.

load that the line of pressure is along the axis of the test piece. A ball-bearing block for this purpose is shown in Fig. 31.

The test pieces as soon as they are removed from the water shall be placed in the testing machine, with a piece of heavy blotting paper on each of the crushing faces, which should be those that were in contact with the mould.

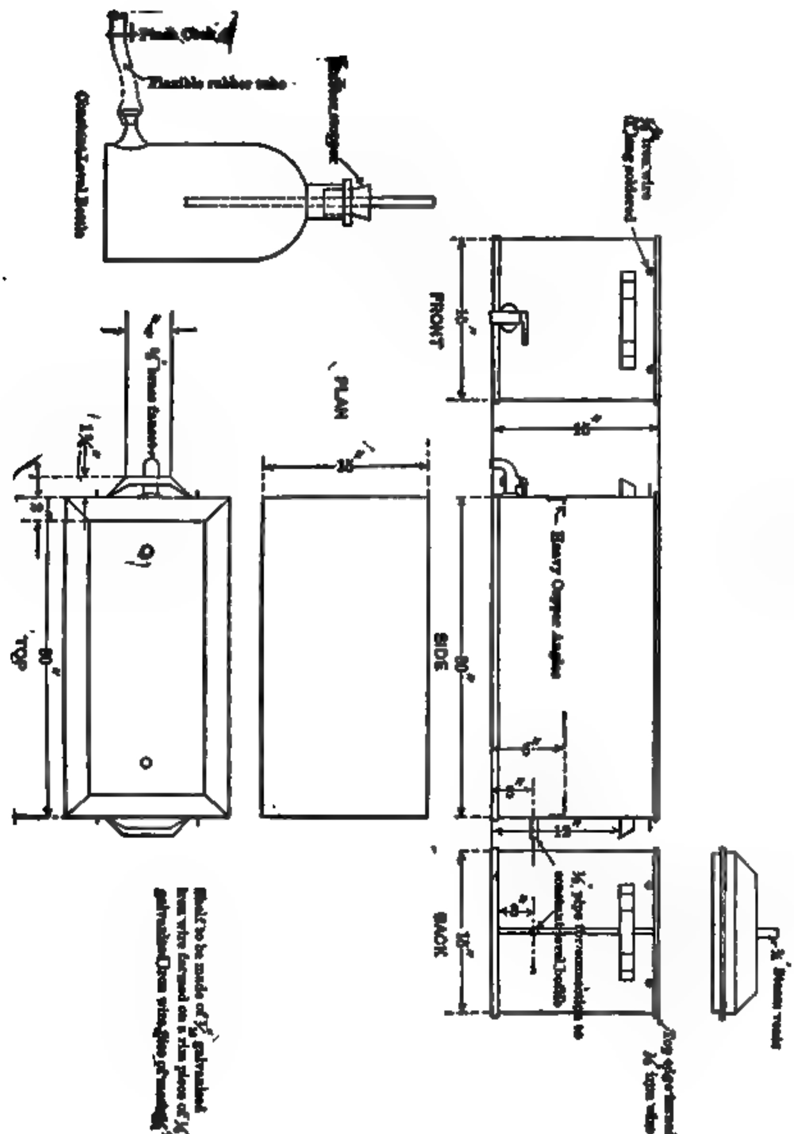


FIG. 22.
APPARATUS FOR MAKING ACCELERATED TEST FOR SOUNDNESS OF CEMENT.

13. *Constancy of Volume.*—The tests for constancy of volume comprise "normal tests," which are made in air or water maintained as nearly as practicable at 21° C. (70° F.), and the "accelerated test," which is made in steam. These tests shall be made in the following manner:

Pats about 3 inches in diameter, ½ inch thick at the center, and tapering to a thin edge, shall be made on clean glass plates about 4 inches square, from cement paste of normal consistency, and stored in a moist closet for 24 hours.

Normal Tests.—After 24 hours in the moist closet, a pat is immersed in water and observed at intervals. A similar pat after 24 hours in the moist closet is exposed to the air for 28 days or more and observed at intervals. The air and water are maintained as nearly as practicable at 21° C. (70° F.).

Accelerated Test.—After 24 hours in the moist closet, a pat is placed in an atmosphere of steam, upon a wire screen 1 inch above boiling water, for 5 hours, the apparatus being such that the steam will escape freely and atmospheric pressure be maintained. The apparatus is shown in Fig. 32.

The cement passes these tests when the pats remain firm and hard, with no signs of cracking, distortion, or disintegration.

George S. Webster, *Chairman.*
Richard L. Humphrey, *Secretary.*
W. B. W. Howe.
F. H. Lewis,
S. B. Newberry,
Alfred Noble,
Clifford Richardson,
L. C. Sabin,
George F. Swain.

CHAPTER XIII.

PLANS AND SPECIFICATIONS.

Purpose of Plans and Specifications.

DETAILED information concerning any proposed work is generally furnished by means of plans and specifications, the latter showing the manner in which the work is to be carried out, and the former its location and extent, as well as certain details in the method of construction that cannot easily be described in the specifications. Generally speaking, the plans should be made first, showing exactly where the work is situated, its bounding limits in each direction, and all details necessary for a thorough knowledge of what is to be done. With the plans before him, the engineer is prepared to describe fully the method of construction. Careful study, however, is necessary so that he may thoroughly understand what is desired and be able to make plain to any prospective bidder just what will be required. He should be careful to see that there is no conflict between the plans and specifications, as this necessarily brings confusion and uncertainty as to what is expected.

Specifications.

The specifications should be concise and explicit, being very careful to make clear exactly what is to be done. As a rule, both the corporation and the contractor will be better served by having this plainly understood. The object of the contractor is to make money; and if, by some trick or obscure wording of the specifications, something is hidden which he will afterwards be called upon to perform, he will be disposed to slight other parts of the work so that he may make up on one thing what he loses on another. Specifications, however, should not be too full, else there is a liability to conflict. An attempt to make anything too plain often results in creating confusion rather than clearness. An example

of this was shown in a contract which, in its bidding blank, required that the contractor should preserve and protect all street railways from any damage. In one section the specifications provided that the contractor should allow the owners of all street railways every facility for shoring up and protecting their tracks. This was plainly a conflict; and when a test case arose, a compromise was effected by which the city paid a material proportion of the extra expense caused by the railway tracks; the railway companies holding that the city could make no contract that would be binding upon them, and the contractor maintaining that if it was his duty to provide the street-car company with facilities for doing their work, it was not incumbent upon him to perform it. If the engineer who drew the specifications had been content with the first clause providing for the contractor to do all work on the street-car tracks at his own expense, there would have been no trouble, but his very attempt to make the matter more binding really released the contractor from his obligation.

The engineer, too, should understand that it is as much his province to have work done well at its lowest possible price as it is to have the work well done. By that is meant that he should thoroughly study the requirements of each case and have such knowledge of the materials to be used that he should not ask for anything more than is necessary. In other words, he should impose no extra cost of construction upon the city or his client in order simply to protect himself.

Contractors to Furnish Plans.

It is customary on some classes of work to make up a set of general specifications and ask the contractors to furnish their own plans. As a whole this is objectionable, and it is doubtful if a contract made under such specifications would be legal under a law which required all contracts to be awarded to the lowest responsible bidder. All plans and specifications should be so made as to allow the greatest competition, for when one contractor bids upon one set of plans and another upon a different set, the result is not one of competitive bidding.

In general work, however, where a commission or board has the power to make contracts in their discretion, and where the work is of such character as to require a special expert, or where the exercise of superior knowledge or ingenuity would arrive at

the same result with less cost, it might be advisable to allow the contractors to prepare their own plans. This necessitates, however, a careful examination of all plans by an engineer who is thoroughly conversant with the matter and who is capable of giving an intelligent and unbiassed opinion as to the most desirable plan. It must be remembered that in every case it is results that are looked for, and that it is proper to use every legitimate method to obtain the best results at the lowest expense. Contractors and bidders, however, have their rights, and it is not fair or honest for any corporation to call for bids or plans unless it is the intention to accept the one that is deemed the most favorable to the interests of the party calling for bids.

Clauses to be Enforced.

The engineer should not insert any clauses in the specifications that are not intended to be enforced. Otherwise he may unnecessarily increase the cost of the work, or the contract will be drawn in such a way that one contractor, knowing the custom of the locality and that certain provisions are not intended to be enforced, will bid lower, and be able to do the work for a less price, than the contractor who bids simply upon the exact meaning of the specifications. All honest contractors wish specifications enforced, for then they know just how to make their figures, just what work will be required of them, and feel that they stand upon an equal footing with other bidders. This is especially necessary in large works where bids are asked for from outside parties.

Description of Subsurface Material.

In preparing plans for work, especially that which requires any subsurface construction, it is always a question as to how much information should be given or advertised as to the character of the underground material. Some cities make a very thorough examination in such cases, and on their plans show the result of their examination—whether water or rock exists, and to what extent. It has always seemed that this was a rather dangerous proceeding, especially in the case of water, which it is difficult to pay for separately. Where rock is encountered in excavation a special price is generally made for paying for it by the cubic yard. In the case of water it is different; and it would seem only fair that if the city or corporation should show water as existing in a certain part of the work, and insert the requirement in the specifi-

cations that all water encountered should be taken care of by the contractor at his own expense, if water should be discovered in other parts of the work the contractor would be entitled to the extra cost of doing the work on account of the existence of the water. This would be a matter very hard for the engineer in charge of the work to adjudicate, and would almost always result in litigation.

When a contractor prepares to bid upon any piece of work, he expects to, and it only seems fair that he should, take such steps as will give him all the necessary information about the character of the material to be encountered as will enable him to put in an intelligent and reasonable bid. If the corporation requiring the work to be done furnishes all information as to where and how it is to be constructed, that would seem to be sufficient in most cases. In some special instances, however, where the work was of a particularly difficult nature, requiring a great deal of preliminary work before any knowledge of the material could be obtained, it might be advisable and economical to all concerned for the corporation to furnish all necessary information. It must be understood, of course, that if the contractor makes a large outlay in a preliminary investigation, it will be added to his bid, and the party for whom the work is to be done will in the end pay for it.

Quantity of Work to be Done.

With the plans and specifications for street work, and in fact for nearly all kinds of work, should go a statement giving, as nearly as can be determined in advance, the exact quantity of work to be performed. By this is not meant the amount of material required in any construction, but simply the aggregate quantities of the different parts of the work. This should be obtained from a careful survey, and a price called for in the bidding blanks for each item on the list. This method shows to the contractor the amount of work required of him, and it also enables the engineer to determine with certainty the lowest bidder, and to ascertain whether the bid is made out intelligently with a proper price for each item.

Lump Sum Bids.

Some people, however, advocate the letting of contracts for a lump sum, on the ground that the contractor in looking over the

work will be apt to omit or forget something and consequently put in a bid for a less amount than he otherwise would. That is, the intention is to get, if possible, a certain amount of work done for nothing. This is neither honest nor expedient, because, as was said before, where a contractor loses on one part of the work he is very apt to make good his loss on another. It is exceedingly difficult, however close and intelligent the inspection, to watch the contractor at all times, and if by the use of sharp practice on the part of the corporation or individual he has been led into making a contract by which he will lose money, it is not to be wondered at that he will attempt to recoup himself at the expense of some portion of the work.

No individual or corporation can afford to have work done for nothing. Good work is worth a good price, and the information placed before the bidder should be of such nature that he can plainly know everything that will be required of him.

Indeterminate Quantities.

It often happens that the quantity of certain parts of the work cannot be determined in advance. If, however, a price is asked for each one of these items, a quantity must be fixed in order to determine the lowest bidder in canvassing the bids; but if this quantity be too small or too great, this difference, when the bidding is close, may make a difference in the lowest bid. Then, too, when the quantities are small, the contractors are apt to specify a large price, as the sum total will not much change the entire bid. To avoid trouble of this kind, especially where work is not to be paid for by assessment, a good plan is for the engineer to determine upon and fix in the specifications a price that will be paid per unit for each of these indeterminate quantities. It has been decided by legal authorities that, even if work were to be paid by special assessment and as the result of competitive bidding, where it was not possible to determine accurately the amount of different kinds of work called for, it would be legal to specify their price in advance, the theory being that there would be less liability to injustice with a fair price specified than to allow the contractors to bid on an uncertainty.

Extra Work.

Another thing that always causes much trouble in all contracts is extra work and claims for extra work. While it often seems im-

possible to provide beforehand for everything that will be required, in most cases it can be done, and certainly always should be if possible. Contractors should always be discouraged from making any application for extras. Specifications generally require that all extra work shall be done only upon a written order of the proper authorities. If no price is fixed in a contract for such extras, a written order should always contain the amount to be allowed for the extra work done, so that when a bill for the same is presented by the contractors there will be no question of the amount of remuneration.

Where the contractor and the engineer are in harmony, extras are very often ordered in by, and performed under, verbal orders, even when this clause is inserted in the specifications. The importance, however, of observing such clause, and in fact all clauses of the specifications, by the contractor as well as the city officials, was seen in carrying out a sewer contract in which the specifications provided that no sheeting left in the work should be paid for unless it was so ordered by a written order from the Board of Public Works. In this particular case sheeting was ordered in verbally by the Engineer of the Board, and a return made of the same by the inspector in charge. When the final estimate was given the Board of Public Works refused to pay for the sheeting, and, in a suit which was brought to settle other disputed points of the same contract, the court decided that the city was not liable for the sheeting because it had not been left in in accordance with the written order as provided by the specifications, although it was ordered in verbally and deemed necessary by the Chief Engineer of the Board.

Alternative Bids.

It is sometimes the practice in receiving bids to allow contractors to make alternative propositions, that is, a proposition to do the work for a certain price if performed with a certain kind of material in a certain manner, or for another price if performed with other material in a certain other manner. This is objectionable, as it makes it possible to have two lowest bidders, depending on the way the work is to be carried out. It also leaves it possible for the contract to be awarded to one bidder at one price, and after the contract is let to substitute the alternative proposition at its price, and so have the work performed eventually by a contractor who

was not the lowest bidder. Wherever possible, the conditions should be so studied beforehand as to be able to decide which material is better for any particular work, and call for bids accordingly. Sometimes, however, the question of deciding is an economical one, and the matter of cost is an important element in the decision. In that event, it is permissible to receive alternative bids, but as a rule the practice should be discouraged.

General Instructions.

Attached to the specifications should be a sheet giving general instructions to bidders, telling what formal requirements are called for and what steps it is necessary to take in order that their bid should be received and be in proper form. In order to facilitate the canvass of bids and to insure uniformity in bidding, blanks should be made out for each bidder, giving estimated quantities upon which bids will be canvassed. In the instructions to the bidder should be inserted a clause telling at what hour all bids are to be in. This time should not be varied from, and as a rule all bids should be opened at the time specified for their reception. It often occurs, if bids are allowed to remain a certain time after they have been received, that one or possibly more may come in between the time of reception and opening. If these should all be high bids, no trouble would occur; but if the lowest bid should happen to be one that was received after the time advertised for the bids to be in, complications would be very apt to arise. Contractors who have complied strictly with all the requirements complain, and rightly too, if these requirements are not lived up to by the city, and it seems no more than just that if the city or corporation calling for bids require the contractor to live up to these requirements, it should do so itself.

Certified Check.

On every work of any magnitude it is customary to have a certified check accompany each bid, in order to indemnify the city from any loss or damage if for any reason the successful bidder should not be able to enter into the contract. It is also sometimes required, in addition to this certified check, that the bidder give the names of the persons or surety company who will sign all bonds for the performance of the work in case the contract should be awarded to the bidder. It does not seem necessary, and in some cases it works hardship, to require both certified check and the

names of the bondsmen. A certified check should certainly be sufficient to indemnify the city for any damage, and in case satisfactory bondsmen could not be provided the city would have recourse to the check.

The amount of this check should be as small as possible and yet give the city adequate security. It is generally customary to require a percentage of the amount of the bid. This, perhaps, for a general rule, is as good as any; although in some contracts where it is necessary for the work to be done as soon as possible, the time lost in readvertising would be of considerable value, while in others the delay would be no material damage, so that it would probably be more satisfactory to establish an arbitrary sum for each contract. Five per cent of the amount of the bid is the ordinary requirement.

Error in Bid.

It is often found or claimed, while the bid is being read, that an error has been made in making out same, and an application made for an opportunity to make a correction. To allow this would be to establish a dangerous precedent. The contractor must take certain chances. He takes work by contract so that he may make more than ordinary day's wages, and if an error should occur so that he is compelled to do a certain amount of work for less than the market price, or bids so high on some item by mistake that he loses his contract, he must abide by the letter of the bid, trusting for his loss in one case to be made up by gain in another. A variation from this rule will open the way for endless trouble, and for claims of errors where none exist.

Withdrawal of Bid.

No changes or withdrawals should be permitted after any bids are opened. If, however, the contractor should tender his bid some hours in advance of the final closing, and wish to make changes in the same, there should be no objection to his having it returned prior to the expiration of the time for the receiving of the bids.

Indorsement of Bids.

In order that there may be no question as to whose bid any package may contain, all envelopes should be indorsed with the name of the bidder and the work which he proposes to carry out.

Bond.

Before any contract is executed by the city, a bond should be signed by responsible parties guaranteeing that the contractor will carry out the provisions of the contract. The amount of this bond must be determined by the nature of the work. It should be a fixed amount, decided much upon the same principle as that governing the amount of the certified check, that is, the damage that the city is liable to be put to from the failure or delay in the carrying out of the work. It should be large enough to provide for any loss of time on account of the necessity of cancelling the contract and readvertising the work, and also to make good any difference in the cost from the original contract price and what was actually required to perform the work. The former must be determined by the location and character of the work, and the latter by the prices for the different items in the contract.

Time for Completion.

All contracts contain the provision that the work shall be done by a specified time or in a specified number of working days, and generally provide for a penalty to be paid by the contractor for each day in excess of the stated time. It is necessary to insert such a provision in all contracts. Otherwise it would be possible for a contractor to begin a piece of work and, after it was partially completed, to leave it for some other and more profitable contract, or to dilly-dally on the street to the inconvenience and detriment of the public at large. The engineer, however, in determining the time should be sufficiently liberal to enable the contractor to finish within the specified time if he uses reasonable diligence.

Penalty.

The question of penalty, however, is one that should be taken up with a great deal of care. It must be considered that it requires two parties to make a contract, and if a penalty is required for any excess of time employed, and no bonus given if the work is performed sooner than the specified time, it is questionable whether such penalty could be enforced. It would seem, too, if the work was of such a nature that the time of completion was important, that it would be just to both parties to require a penalty if the time limit were exceeded, and to pay a bonus if the work were completed inside of the specified time. This is the general practice on large and very important contracts. If, however, the contractor

has bid a certain price for agreeing to finish within a certain time, which possibly is higher than that of the bidder who proposes to do it in a longer time, the question is different, for in the latter case the contractor receives extra compensation for early completion, and if he exceeds the limit, a penalty should and undoubtedly could be enforced.

Maintenance.

In specifications for street improvements of any kind it is generally provided that the work shall be maintained and kept in repair for a certain length of time. When asphalt pavements were first introduced in this country it was necessary for the contractor to agree to keep the pavement in repair for five years in order to have any city adopt them. The material was new and no city would run the risk of paying the price asked for an unknown and uncertain pavement; so that when the contracts were made they contained a clause binding the contractor to keep them in good repair for five years, whereby the city in each case was certain of a good pavement for a definite period. The conditions, however, at the present time are very different. Asphalt pavements are well established and have come to stay, and the question of guarantee, as to its length and exact meaning, is very important. Nearly all cities, however, require a guarantee of five and the City of Buffalo ten years.

Payments.

The method of paying for the original pavement and of keeping it in repair varies in different cities. In some places the original cost is paid by special assessment, and the repairs by a general tax. In such cases as this the guarantee period must be carefully determined upon. It has been adjudicated in the courts many times, and the established limit has been that a guarantee period of five years can be enforced in a contract for an asphalt pavement the payment for which is derived by general assessment, but that it cannot when the cost of repairs or repaving is defrayed by general tax. In New York City all contracts for asphalt pavement are made with a guarantee period of five years, where formerly it was ten and sometimes fifteen years.

Guarantee.

While the original asphalt pavements were laid with the inten-

tion of being kept and maintained, without any expense to the city, for a period of five years, it is questionable, unless specifically defined, just what is meant by the terms " guarantee " and " maintenance." Cities as a rule consider that it means that they shall be at no expense whatever for the care of these pavements during the guarantee period. The contractors, however, maintain that their guarantee covers simply that the work shall be done in a proper manner and with good materials; that if any unforeseen circumstances arise, causing damage to the pavement, they are not compelled to repair it without special compensation. Fires, settlements of sewers, causing breaks in the pavement, are all cases in point. Specifications, therefore, should clearly define just what is intended, and it would seem that when a guarantee is given that the work will be done properly and good materials furnished, nothing more could be required or expected of the contractor, on the principle laid down before, that the contractor should know all of the conditions under which he bids, and that the city should pay the cost of any unforeseen damage to the pavement.

As to how long the guarantee shall run is also a mooted question. For some reason five years has seemed to be taken as the unit for asphalt pavement, although in many cases contracts have been made with ten and fifteen years' guarantee. Sometimes the cost of guarantee has been included in the original price per square yard. In other cases the contract has provided for the original price per square yard, the pavement to be maintained without expense for five years, and then for an additional five years for a specified price per year.

In 1898 a contract for laying asphalt pavement was made in Minneapolis, Minn., for a certain price per square yard, with a ten years' guarantee, and the additional price of 10 cents per yard per year for a second period of ten years.

Newark, N. J., has asked for bids for a five-year guarantee, and has specified an additional price of 5 cents per yard per year for an additional ten years.

Other cities have called for stipulated prices per yard for a certain guarantee period, with the option of making an additional contract for a specified price per yard per year.

Previous to consolidation New York City required asphalt pavements paid for by the general public to be maintained for fifteen

years. The specifications provided that on the completion of the work 70 per cent of the contract price should be paid to the contractor. Of the remaining 30 per cent, one-tenth was to be paid each year, beginning five years from the date of final acceptance. The present contracts call for a guarantee of ten years with a reserve of 20 per cent, one-fifth of which shall be paid each year, beginning, as above, five years from date of completion of the work.

The old city of Brooklyn required a five-year guarantee on all asphalt pavement, but made payment in full upon the completion of the work, relying upon the bond wholly for the carrying out of the maintenance portion of the contract. Omaha, Neb., also required five years' maintenance, but reserved 15 per cent of the contract price until the end of the guarantee period. The contractor was, however, allowed to purchase city bonds and deposit them with the city treasurer, in lieu of this reserve, and thus draw interest upon the amount withheld.

With the present knowledge of asphalt it would seem best to require a five years' guarantee.

Upon granite, brick, or other pavement, where it can soon be determined whether there are any faults in either material or construction, no long-time guarantee is necessary. At the end of nine months any defects from the above causes will have been developed and can be repaired, and there would be no good reason for requiring any reserve fund to be longer held.

When the work is completed the entire amount should be paid less ten or fifteen cents per yard of pavement, according to the character of the work. When the guarantee period has expired and any necessary repairs have been made, the above amount should be paid the contractor.

Details of Work.

To just what extent it is proper for any city or corporation to specify the details with which work shall be carried on when it is to be maintained for a specified time is often questioned. The contractor claims that he is under contract to maintain pavement for a certain length of time, and it is for his best interest to do the work in a proper manner, and that he should be allowed to do it according to his judgment. The engineer, on the other hand, argues that the contractor knew the specifications and requirements

before he bid, and if he could not get good results from those specifications, he should either have protested before putting in his bid or making his contract, or else refused to have anything to do with the work.

The contention of the contractor is hardly valid, for even if he enter into a contract to maintain the pavement for a term of five years or fifteen years, he is also under contract to leave it in good condition at the end of that time, and it is for the city's interest to have it left in such condition at the end of the guarantee period that it will last for as long a time as possible afterwards, with little repair. So that there seems to be no question but that the city has the right to enforce all the requirements of the specifications. This assumes, however, that the city will, as in fact it must, employ a competent engineer to make the specifications so that no impossible requirements are inserted.

Unbalanced Bids.

Another source of great trouble to the engineer in the carrying out of contracts is unbalanced bids. When different items are given for the amount of work to be performed and there is any uncertainty as to these quantities, the shrewd contractor often goes over the work in advance of the bidding, in order to verify these quantities and make his own estimate as to the probability of their being correct. If he thinks they are liable to be varied in the carrying out of the work, he will make a high price for one item and a low price for another, so that he will be the lowest bidder on the quantities as given, but be higher on the work as completed. While this would do no harm on contracts where the quantities are not changed, it often does cause great trouble if for any reason it is desired to make any changes. It also permits the engineer, if in collusion with the contractor, to change some items, reducing those of small price and increasing those of the higher price, to the great benefit of the contractor.

It is not always easy to determine what is an unbalanced bid. Often the conditions may be such that one contractor may be able to do a piece of work, or one portion of it, for a price which would seem to make it an unbalanced bid, when it was strictly legitimate. In some way he might have an advantage over another contractor. But there are cases where it is plain to be seen on the face of it that the bid is unbalanced. In every case of this kind the bid

should be thrown out without hesitation, provision having been made in the specifications for such action. One of the best, if not the best, of the methods of overcoming unbalanced bids is that adopted by Jersey City, N. J. It it customary there for the Engineer, after carefully studying the market, to establish a price for each item that is called for in the work, and require all bidders to bid a certain percentage above or below this standard, and apply this percentage to every item of the schedule. This absolutely prevents any trouble from unbalanced bids, and certainly seems fair to both city and contractor. This plan has been in use in the Sewer Bureau of the Borough of Brooklyn for some years with very satisfactory results.

Combinations among Contractors.

Another plan of protecting the city, not from unbalanced bids, but from contractors making combinations among themselves, has been adopted in Toronto, Can. There the City Engineer himself puts in a bid to the city, agreeing to do the work for what he considers a fair and reasonable price. If he should be the lowest bidder, the work is awarded to him and carried out by the city by day's labor under the Engineer's supervision. The contractors, knowing this is to be done, realize that there is no opportunity for obtaining an extravagant price, and in consequence generally bid with the expectation of a reasonable profit.

Plans:

The plans for the paving of a street should show first the limits of the contract on the main and on all of the cross streets. It should show the location of all the cross-walks to be laid, and all special work called for. It should show the cross-sections of the finished pavements, and give every detail of construction. The profile should show the amount of excavation and embankment for the entire length of the street. It should show the existing surfaces of both property lines and also the centre, so that the contractor would know in exactly what parts the excavation and embankment were located, and thus be able to determine the distance that the earth would be hauled. The plans should also show the quantities of each kind of work required. After the contract has been awarded, the contractor should sign the plans, which should become a part of the contract, as should also the specifications.

The foregoing remarks on the Plans and Specifications are general, although mainly referring to pavement-construction.

The specifications which follow are suggested for general use for the original improvement of streets that have never been graded. They are made up of different specifications of this country, modified according to the ideas of the author as the result of thirty years' experience in municipal work. They embody what is considered the best practice of the engineers of the country. The specifications for bitulithic were furnished by the Warren Bros. Company.

While these specifications are general, they are supposed to be so made up that they can be applied and used in any city in the country by making the changes required by local conditions and laws. Some modifications would be required for repaving work, but for the actual work of pavement-construction they are recommended for general use.

Notice to Bidders.

Bidders must satisfy themselves, by personal examination of the location of the proposed work and by such other means as they may prefer, as to the accuracy of the estimated quantities, and shall not, at any time after the submission of a bid, dispute or complain of such statement or estimate of the Engineer, nor assert that there was any misunderstanding in regard to the nature or amount of the work. The quantities given herewith are supposed to be accurate, and are estimated by the City Engineer for the purpose of determining the lowest bidder, but final payment will be made on measurements made of work actually performed.

Each bidder must deposit with the City Engineer, previous to making his bid, samples of the materials he intends to use, according to the character of the work called for, as follows:

1. A specimen of refined asphalt, with a certificate stating where the material was mined.

2. A specimen of the asphaltic cement, with a statement of the formula to be used in the composition of the mixture for the wearing surface.

3. A sample of not less than four pounds of the paving mixture as it will be laid upon the street.

4. Not less than twelve bricks which are proposed to be used.

5. Not less than twelve wood blocks such as are proposed to be used.

6. A sample block of either stone or asphalt.

7. Additional specimens of all kinds must be furnished as often as may be required during the progress of the work.

No bid will be received or considered unless the deposits of material referred to above are made with the City Engineer within the time prescribed.

Any bid accompanied by samples which do not come up to the standard required by these specifications will be regarded as informal.

No proposals will be received or considered unless accompanied by either a certified check drawn to the order of the Comptroller, or of money equal to five per cent of the amount of the security required for the faithful performance of the work. Such check or money must not be inclosed in the sealed envelope containing the proposal, but must be handed to the officer or clerk who has charge of the proposal-box, and no proposal can be deposited in said box until such check or money has been examined and found to be correct. All such deposits, except those of successful bidders, will be returned to the persons making the same after the contract is awarded. If the successful bidder shall refuse or neglect, within five days after notice that the contract has been awarded to him, to execute the same, the amount of the deposit made by him shall be forfeited to and retained by the city . . . as liquidated damages for such neglect or refusal; but if he shall execute his contract within the time aforesaid, the amount of his deposit shall be returned to him.

SPECIFICATIONS FOR GRADING AND PAVING WITH ....PAVEMENT ON A CONCRETE FOUNDATION.

(1) The work to be done shall consist of grading the entire with of the street, setting curbstones and heading-stones if required, laying and relaying the cross-walks where so required, and laying ——— pavement on a concrete foundation on the roadway of ——— Street from ——— Street to ——— Street.

(2) All the materials furnished, and all the work done, which, in the opinion of the City Engineer, shall not be in accordance

with the specifications shall be immediately removed, and other materials furnished, and work done, that shall be in accordance therewith.

Before any materials are placed upon the street the City Engineer shall approve of the quality and finish of samples of the same which shall be furnished at his office. These shall include the samples referred to on page , and also a sample of the paving-blocks to be used in the work.

(3) The work under this specification is to be prosecuted at and from as many different points in such part or parts of the streets on the line of the work as the City Engineer may, from time to time, determine, and at each of said points inspectors may be placed on the day designated for the commencement of the work.

(4) The right to construct any sewer or sewers, receiving-basins or culverts, or to build up or adjust any manholes, or to reset or renew any frames and heads for sewer or subway manholes, or for water or gas stop-cocks, or to lay gas- or water-pipes, or to construct necessary appurtenances in connection therewith in said street or avenue, or to grant permits for house-connections with sewers, or with water- or gas-pipes, or for any other underground or subway construction, or to alter and relay railroad-track, at any time prior to the laying of the new pavement over the line of the same, is expressly reserved by said City Engineer; and said City Engineer reserves the right of suspending the work on said pavement, on any part of the line of said street or avenue at any time during the construction of the same, for the purposes above stated, without any compensation to the Contractor for such suspension other than extending the time for completing the work as much as it may, in the opinion of the said City Engineer, have been delayed by such suspension; and the said Contractor shall not interfere with or place any impediment in the way of any person or persons who may be engaged in the construction of such sewer or sewers, or in making connections therewith, or doing other work above specified, or in the construction of any receiving-basins or culverts.

(5) In case there shall be at the time stipulated for the commencement of the work any earth, rubbish, or other incumbrance (building material for which a proper permit has been issued is not

herein included) on the line of the work, and not required by the Department, the same is to be removed at the expense of the Contractor.

(6) *Grading.*—The entire width of the street is to be regulated and graded, in accordance with the grade as shown upon the profile or map on file in the office of the City Engineer. The carriageway and sidewalks to be shaped as per cross-section shown on the plans. That portion of the street which is above the grade-lines to be excavated, and such parts as are now below the grade-lines to be filled in, in the manner hereinafter provided, and the surplus earth not used for filling to be removed from the street. If, owing to the unfitness of the present material for a foundation, it is considered necessary by the Engineer to remove it to a greater depth and substitute other material, such removal and refilling will be paid for by the cubic yard at the prices bid for excavation and embankment, except as hereinafter specified.

The slopes in excavation shall be one and a quarter horizontal to one vertical.

The embankment shall be formed of good, wholesome earth, sand, gravel, or clean ashes. No house-ashes containing garbage or rubbish, no vegetable matter or *débris* of any kind will be allowed. The slopes of the embankment shall be one and a half horizontal to one vertical.

No allowance will be made the Contractor in any case for settlement, shrinkage, or additional slopes. If any material shall be encountered in excavating which is considered especially adapted for the foundation, it shall be placed aside when so directed, and used at the proper time for that purpose.

The embankment is to be made from material excavated on the street where there is a sufficient quantity of such material. Where the amount of excavation is less than the amount of embankment the Contractor must supply the deficient material. The price bid for grading shall be applied to whichever amount shall be in excess.

(7) *Grading Sidewalks.*—All stone shall be dug out of the sidewalks, to three inches below the finished grade thereof, and the holes filled to the grade of the sidewalks with clean sand or gravel. The sidewalks to have a slope of six inches from the line of the street to the curb.

(8) *Preparation of Roadbed.*—The carriageway shall be thoroughly rolled with a ten-ton steam-roller, all soft spots having been excavated and filled with gravel or other suitable material until the whole roadway has been thoroughly consolidated and finished to the following depths below the surface of the completed pavement:

For asphalt nine inches; for asphalt block nine inches; for granite on concrete twelve inches; for Medina sandstone on concrete thirteen inches; for bitulithic on concrete.........inches; for wood block on concrete ten inches; and for vitrified brick eleven inches.

(9) *Cross-walks.*—The cross-walks shall consist of three courses of stone. The stone to be of the same quality as the blocks, the side and ends to be squared and free from all winds, seams, and other imperfections; each stone to be not less than four feet nor more than six feet in length, one and one-half feet wide, and not less than six nor more than eight inches thick throughout, to be dressed to an even face on top, sides, and end. The ends of the stones are to be cut to such curves, when necessary, as may be directed, and all to form close and even joints from top to bottom when laid. Where cross-walks are at right angles to the line of travel all joints shall be cut with a bevel of six inches.

The Contractor shall lay one row of stone blocks between the courses of bridge-stones.

The cross-walk stones must be firmly bedded on the same foundation as the pavement, and set true to line and grade. The courses must be so laid that the transverse joints will be broken by a lap of at least one foot.

Any old cross-walks now on the line of the street or adjacent to the new pavement shall be relaid by the Contractor, when so directed, in the manner above described, without any charge therefor.

(10) *Curbstones.*—Curbstones shall be free from seams, checks and other imperfections, and shall be tough, and hard, equal in quality to the best stone. They shall be sixteen inches in depth and not less than three and one-half feet in length, averaging on each block not less than four and one-half feet in length, and be.....inches in thickness, except as noted or bottom of curb.

The face for a depth of nine inches and the top on a bevel of one-half inch in its width of five inches shall be dressed to a

surface which shall be out of wind and shall have no depressions measuring more than one-quarter of an inch from a line or straight edge of the same length as the curbstone. The remainder of the face shall be free from projections of more than one-half an inch, and the back for three inches down from the top shall have no projections greater than one-quarter of an inch measured from a plane at right angles to the top. The bottom of the curb shall be rough squared with a width of not less than three inches.

For the full width of the stone for a distance down of four inches from the top, and there below for a width of one and one-half inches back from the face to a point twelve inches below the top of the curb, the ends shall be squarely jointed with no depression greater than three-eighths of an inch, measured from a straight edge. Curved curb corners shall be cut with true radial joints and be set accurately to such a radius as may be required in three-foot lengths. It shall be paid for as straight curb and must comply in all respects with the above requirements therefor. The cost of excavation necessary for curb setting and of the concrete for curb foundation shall be included in the price bid per linear foot of curb.

Each curb stone shall be set truly to line and grade on a face batter of one and one-half inches in its depth.

All curb, unless otherwise directed, shall be set in a bed of concrete six inches in depth and shall have a backing of concrete six inches in thickness, extending to within four inches of the top, as shown in detail plan. The concrete bed shall be laid immediately before the curb is set, and the backing put in place as soon as set, and as much of the concrete foundation for the pavement as may be directed, which shall not be less than one foot; the object being to obtain a uniform and well-bonded mass of concrete behind, under, and in front of the curb. The concrete shall be similar to that described for pavement foundation except that the maximum size of the stone shall be one and one-quarter inches. When set, the corners of the top shall be in a straight line and the face of a plane surface.

Should the concrete in front of the curb have set before that on the remainder of the street shall have been laid, the surface shall be carefully cleaned and thoroughly wet before any fresh concrete is placed against it.

(11) *Heading-stones.*—When asphalt, bitulithic, wood or brick pavement joins the pavement of another kind or an unpaved street, heading-stones, not less than five inches thick and not less than twelve inches in depth and in lengths of not less than two feet, shall be set between the new and the old pavement. They shall be set upon and firmly bedded in a bed of concrete six inches in depth. These heading-stones may be of bluestone, granite, or other approved stone, and the grade of the adjacent surface, whether paved or unpaved, shall be adjusted to that of the new pavement without extra charge therefor. The heading-stones will be paid for as pavement, and must be included in the price bid therefor.

(12) *Concrete.*—All concrete used in the work shall be made of one measure of Portland cement, measured in the original package, three measures of sand, and six measures of broken stone and be six inches in thickness. If the mixing is done by hand, the cement and sand shall be thoroughly mixed dry and then made into mortar with as little water as possible, after which the stone, which shall have been previously drenched with water, shall be added, and the mass thoroughly mixed until all of the stones shall have become coated with mortar, when it shall be promptly placed into position and rammed until the water flushes to the surface. The mixing shall be done upon suitable wooden platforms as may be directed by the Engineer.

If a concrete-mixing machine be used, the cement and sand shall be mixed as above, and precaution must be taken to insure the proper proportion of each of the materials, so that the resultant mixture shall be uniform in quality. The cement, sand, and stone must be placed upon board platforms and kept free from dirt.

Great care must be exercised to make the surface of the concrete exactly parallel to and * ——— inches below the finished pavement. The concrete shall be protected from the weather until set. Should the concrete at any time be considered by the Engineer to be poorly mixed or not to be setting properly, such portion shall be taken up and replaced with satisfactory material.

* Where a mortar cushion is required for any block pavement, said cushion shall be considered as part of the concrete base and paid for as such.

The cement used shall be equal to the best quality of Portland American cement. It shall be delivered on the street at least forty-eight hours before the mixing of concrete is commenced, and no cement shall be used until it shall have been tested, and accepted by the Engineer.

The cement shall be of uniform quality and briquettes of one square inch section shall develop the following tensile strength:

Neat—twenty-four hours in moist air	200 pounds
Neat—one day in moist air, six days in water	450 "
One part cement, three parts standard sand, one day in moist air, six days in water	175 "

The sand shall be good, clean, coarse, sharp sand, free from loam or dirt.

The stone shall be equal in quality to good limestone, entirely free from dust and dirt, and of such size that it will pass through a screen having holes two inches in diameter, and be retained by a screen having holes one-fourth inch in diameter and as evenly graded between the two extremes as possible.

No concrete can be used which shall have been mixed more than thirty minutes. No carting or wheeling will be allowed on the concrete until it is sufficiently set. When connection is to be made with any section which shall have set or partially set, the edge of such section must be thoroughly cleaned and wet so as to insure a good bond with the new work.

Asphalt Pavement.

(13) *a.* The pavement proper shall consist of a wearing surface 2 inches thick and a binder course 1 inch in thickness for common binder and 1½ inches in thickness for close binder for heavy traffic.

b. Asphalt.—The asphalt shall be either natural or asphalt produced from the distillation of petroleum oil.

Crude, natural, solid asphalt shall mean any natural mineral bitumen, either pure or mixed with foreign matter, from which, through natural causes in the process of time, the light oils have been driven off until it has a consistency harder than 100 penetration at 77° F. At least 98½ per cent of the contained bitumen in the refined asphalt which is soluble in carbon bisulphide shall be soluble in cold carbon tetrachloride.

Asphalt from Petroleum Oil.—Asphalt from petroleum oil shall be produced by the careful distillation of asphaltic petroleum with continuous agitation until the resulting bitumen has a consistency not harder than 30 penetration at 77° F.

All shipments of material shall be marked with a lot number and penetration, and ten samples taken at random from each lot shall not vary more than 15 per cent from the average penetration, providing no part of any shipment shall be below 30 penetration at 77° F.

The solid bitumen so obtained shall be soluble in carbon tetrachloride to the extent of 98½ per cent.

When 20 grams of the material are heated for five hours at a temperature of 325° F. in a tin box 2½ inches in diameter, after the manner officially prescribed, it shall not lose over 5 per cent by weight nor shall the penetration at 77° F. after such heating be less than one-half of the original penetration.

The solid bitumen at a penetration of 50 shall have a ductility of not less than 20 centimeters nor more than 85 centimeters at 77° F. If the penetration varies from 50 an increase of at least 2 centimeters in ductility will be required for each 5 points in penetration above 50, and a corresponding allowance will be made below 50 penetration. This test shall be made with a briquette of cross-section of one square centimeter, the material being elongated at the rate of 5 centimeters per minute. (Dow Moulds.)

c. Flux.—The fluxing material may be a paraffine or an asphaltic residuum, which shall be tested with, and found suitable to, the asphalts to be used.

The residuums must have a penetration greater than 350° with a No. 2 needle at 77° F. under 50 grams weight for one second.

All residuums shall be soluble in cold carbon tetrachloride to the extent of 99 per cent and must remain soft after heating for 5 hours at 400° F.

The paraffine residuum shall have a specific gravity of 0.92 to 0.94 at 77° F. It shall not flash below 350° F. when tested in the New York State Closed Oil Tester, and shall not volatilize more than 5 per cent of material when heated 5 hours at 325° F. in a tin box 2½ inches in diameter, as officially prescribed. The

residue after heating shall flow at 77° F. and shall be homogeneous and shall show no coarse crystals.

Asphaltic residuum shall have the same general characteristics as paraffine residuum except that the specific gravity shall be not less than 0.98 nor more than 1.04 at 77° F. The asphaltic residuum after evaporation at 500° F. to a solid of 50 penetration shall have a ductility of not less than 30 centimeters. (Dow Method.)

d. Asphaltic Cement.—The asphaltic cement prepared from materials above designated shall be made up from the refined asphalt or asphalts, and the flux, where flux must be used, in such proportions as to produce an asphaltic cement of a suitable degree of penetration. The proportion of the refined asphalt comprising the cement shall in no case be less than 60 per cent by weight.

Refined asphalts and flux used in preparing the cement shall be melted together in a kettle at temperature ranging from 250° to not over 375° F. and be thoroughly agitated when hot by air, steam or mechanical appliances, until the resulting cement has become thoroughly mixed into a homogeneous mass. The agitation must be continued during the entire period of preparing the mixtures. Cement shall always be of uniform consistency, and if any portion should settle in the kettle between intervals of using the same, it must be thoroughly agitated before being drawn for use.

The asphaltic cement shall have a penetration of from 40 to 75, which shall be varied within these limits to adapt it to the particular asphalts used in the paving mixture and to the traffic and other conditions.

When 20 grams of the asphaltic cement of the penetration to be used in the paving mixture shall be heated for five hours at a temperature of 325° F. in an oven as officially specified, there must not be volatilized more than 5 per cent of the bitumen present, nor shall the penetration at 77° F. after such heating be less than one-half of the original penetration.

A briquette of the asphaltic cement when at a penetration of 50 having a cross-section of one square centimeter shall elongate to the extent of not less than 20 nor more than 85 centimeters at 77° F. If the asphaltic cement as used in the paving

mixture varies from 50 penetration, an increase of at least 2 centimeters in ductility will be required for each five points in penetration above 50, and a corresponding allowance will be made below 50 penetration. (Dow Moulds.)

e. Sand.—The sand shall be hard-grained and moderately sharp. It shall be so graded as to produce, in the finished surface mixture, the mesh requirements elsewhere specified. It shall contain not to exceed 6 per cent of sand that will pass a No. 200-mesh sieve.

f. Inorganic Dust.—Inorganic dust shall be finely powdered carbonate of lime, quartz, other satisfactory inorganic dust, or Portland cement. It must be of such a degree of fineness that the whole of it shall pass a 30-mesh screen and at least 66 per cent a 200-mesh screen.

g. Binder Stone.—Binder stone shall be composed of hard, clean broken stone, all of which shall pass a screen having circular meshes 1 inch in diameter and shall be graded in size from 1 inch diameter down so as to produce a mineral aggregate of the following additional requirements:

Not less than 35 per cent of the total shall be retained by a 1-inch round-mesh screen;

Not less than 30 per cent of the total shall pass a ½-inch round-mesh screen;

Not less than 10 per cent nor more than 20 per cent of the total shall pass an 8-mesh per linear-inch screen.

Sand can be added if necessary to produce the above requirements.

h. Binder—Common.—The stone heretofore described for binder shall be heated in suitable appliances to not more than 325° F. and then thoroughly mixed by machinery with asphaltic cement, heretofore described, at 250° to 325° F., in such proportions as to thoroughly coat the stone and all fine particles of the mineral aggregate and produce a binder mixture having light and gloss without an excess of asphaltic cement. The exact amount must be determined by the character of the mineral aggregate.

Binder—Close.—The binder stone heretofore described shall be mixed with sand and asphaltic cement at 250° to 325° F.

as herein specified, in such proportions that the resulting aggregate will contain by weight material passing a 10-mesh screen between 25 and 35 per cent, and bitumen in quantity from 5 to 8 per cent, so as to contain a minimum of voids.

The binder shall be spread upon the street at a temperature of from 250° to 325° F., and raked to a uniform surface of such a depth that after being rolled and thoroughly compacted it shall have an average thickness of 1 inch for common and 1½ inches for close binder. The surface after compression shall show at no place an excess of asphaltic cement.

i. Wearing Surface.—The wearing surface shall consist of asphaltic cement, sand and stone dust in such proportions that the finished pavement mixture shall conform to the following composition by weight:

	Per cent.
Bitumen (soluble in carbon bisulphide)	9½ to 12
Mineral aggregate passing 200-mesh sieve	8 to 15
" " " 80 " "	10 to 35
" " " 40 " "	20 to 50
" " " 10 " "	8 to 35
" " retained on a 10-mesh sieve	0

Sand and asphaltic cement shall be heated separately to about 300° F. The maximum temperature of the sand at the mixers shall in no case be in excess of 375° F., and the maximum temperature of the asphaltic cement shall not exceed 325° F. at the discharge pipe. Stone dust shall be mixed with the hot sand and in the required proportions, and then these shall be thoroughly mixed with the asphaltic cement at the required temperature and in the proper proportions in a suitable apparatus so as to effect a thoroughly homogeneous mixture.

The above mixture shall be carried to the street at a temperature ranging from 250° to 325° F. and spread upon the binder to such a depth as will insure a thickness of 2 inches after ultimate compression. This compression shall be attained by first smoothing the surface with a hand-roller or a light steam-roller, after which hydraulic cement shall be swept over it, when the pavement shall be rolled with a roller weighing not less than 200 pounds per inch width of tread, until no impression is made upon the surface. A space of 12 inches next the curb shall

be coated with asphaltic cement and the same ironed into the pavement with hot smoothing irons.

j. No portion of the pavement either wearing surface or binder shall be laid when in the opinion of the Engineer the weather is unsuitable.

Asphalt Block Pavement.

(14) *a.* The asphalt blocks shall be of the following dimensions, viz.: twelve inches long, five inches wide and three inches deep. Variations from these dimensions, exceeding one-eighth of an inch in width or depth, or one-quarter of an inch in length, will be sufficient cause for the rejection of any block.

The blocks shall be composed of:

Asphaltic cement,
Crushed trap rock and
Inorganic dust.

The asphalt and asphaltic cement shall be of the same grade and quality as that specified for sheet asphalt.

When refined asphalt is not already of the proper consistency, an asphaltic cement shall be prepared by fluxing refined asphalt with heavy petroleum oil or other approved softening agent, complying with the above specifications, at a temperature between two hundred and fifty degrees and three hundred and fifty degrees Fahrenheit, and in such proportion as to produce an asphaltic cement within the limits of forty and seventy penetration, when tested at seventy-seven degrees Fahrenheit.

As soon as the fluxing agent is added the entire mass shall be agitated by an air blast or other suitable appliance and the agitation continued until a homogeneous cement is produced. The asphaltic cement must never be heated to a temperature exceeding three hundred and fifty degrees Fahrenheit. If asphaltic cement containing over ten per cent of foreign material is kept in storage, it must be thoroughly agitated when used.

The crushed trap rock used shall be from clean, newly-quarried rock and shall be the product of a roller crusher. No weathered rock or dust-covered crushed rock shall be used. The shape of the crushed rock shall be as nearly cubical as possible,

in no case having a maximum dimension greater than three times the minimum dimension. All of it shall pass a screen having circular holes one-fourth of an inch in diameter. Not less than forty per cent shall be retained on a twenty-mesh per linear inch screen, and not less than twelve per cent shall pass a one-hundred mesh per inch screen. If the crushed stone does not contain the desired fine material, mineral dust can be added to make up the deficiency, and in any case not less than six per cent of such mineral dust shall be used in the manufacture of the blocks.

The inorganic dust shall be as specified for sheet asphalt.

The materials complying with the above specifications shall be mixed in such proportions by weight, depending on their character, as shall be determined by the Engineer, but whatever the character of the asphalt or of the asphaltic cement used, the blocks shall yield not less than five and three-quarters nor more than eight per cent of bitumen soluble in carbon bisulphide.

The block shall have a specific gravity of not less than two and five-tenths and after having been dried for twenty-four hours at a temperature of one hundred and fifty degrees Fahrenheit, they shall not absorb more than one per cent of moisture when immersed in water for seven days.

b. Upon the surface of the concrete foundation, prepared as above described, shall be spread a bed of cement mortar one-half inch in thickness, which shall bring the thickness of the complete foundation up to six inches. This mortar surface shall be composed of a slow-setting Portland cement and clean, sharp sand, entirely free from pebbles over one-eighth inch in diameter, and mixed in the proportion of one part of cement to two parts of sand, until the sand and cement show an evenly blended color. This shall then be mixed with the minimum amount of water required to make a mortar of very stiff consistency. This mortar bed shall be struck to a true surface exactly parallel to the top of the finished pavement and three inches below it.

Upon this mortar surface the blocks shall be immediately laid with close joints and uniform top surface. The blocks shall be laid by the pavers standing upon the blocks already laid, and not upon the bed of mortar. The blocks shall be laid at right angles with the line of the street, except at street intersections, where they shall be laid diagonally, and with such crown as the

Engineer may direct; and in such a manner that all longitudinal joints shall be broken by a lap of at least four inches. The blocks, shall be so laid as to make the lateral joints as tight as possible consistent with keeping a good alignment of the courses across the street, and the longitudinal joints shall be immediately closed by pressing each course in the direction of its length by a lever. When thus laid the blocks shall be immediately covered with clean, fine sand, entirely free from any loam or earthy matter, perfectly dry, and screened through a sieve or screen having not less than twenty meshes to the inch. This sand shall be swept over the surface until all joints are and remain filled, and shall be allowed to remain on the pavement not less than thirty days or during such time as the action of the traffic on the street shall require to thoroughly grind the top sand into all joints. Surplus sand shall be removed from the pavement when directed by the Engineer.

After the blocks are laid and sanded, the pavement must be protected from all vehicular traffic for a period of forty-eight hours.

Bitulithic Pavement.

(15) *a. Weaving Surface.* On the concrete foundation prepared as hereinbefore specified shall be laid the following wearing surface composed of hard crushed stone, sand and bituminous cement to have the thickness when compressed of two inches.

b. In preparing the mineral aggregate for the above wearing surface the following method and apparatus shall be used. The maximum size stone should be about one-half the thickness of the wearing surface. The varying sizes of stone approximately proportioned shall be fed into an elevator terminating and discharging into a rotary drier. After heating the stone shall be elevated and passed through a rotary screen having sections with various sized openings. The minimum screen opening shall be one-tenth inch and the maximum shall not be greater than one and one-half inches. The difference in the width of openings in successive sections shall not exceed one-fourth inch in sections having openings smaller than one-half inch and shall not exceed one-half inch in sections having openings greater than one-half inch. The several sizes of stone thus separated

by the screen sections shall pass into a bin containing sections or compartments corresponding to the screen sections. From these compartments the stone shall be drawn into a weigh box resting on a multi-beam scale. The several sizes of mineral aggregate, after being separately weighed shall be dropped into a "twin pug" mixer where bitulithic cement shall be added in sufficient quantity to coat all particles and fill such voids as remain unfilled by the proportionment of the mineral aggregate. The aggregate shall be so proportioned and such an amount from each bin shall be used as to secure in the aggregate inherent stability, density, freedom from voids, and resistance to displacement, and a mixture which, when combined with the bitulithic cement and compacted together will form a bituminous street pavement structure containing mixed mineral ingredients of such grades as to give the structure inherent stability, and one in which the largest and smallest pieces are associated with each other indiscriminately throughout the structure, and in which the plastic bituminous composition permeates the entire mass, uniting the various sized particles thereof; filling the voids and forming the wearing surface. If the crushed stone does not contain enough finely divided particles to fill the small voids in the aggregate the deficiency of these finely divided particles shall be made up by the addition of sand or other suitable fine mineral matter.

c. The mineral aggregate shall be heated and mixed with the bitulithic cement at a temperature consistent with good workmanship. The whole mixture shall be hot enough when reaching the street to be capable of being spread and raked without difficulty and not so hot as to injure the bitulithic cement.

Surface Finish.—After rolling the wearing surface, there shall be spread over it a thin coating of bitulithic flush-coat composition by means of a suitable flush-coat spreading machine, so designed as to spread quickly over the surface a uniform thickness of flush-coat composition. This spreading machine shall be provided with a flexible spreading band and an adjustable device for regulating, to any desired amount, the quantity and uniformity of flush-coat composition to be spread.

There shall be spread over the flush-coat composition, in at least two coats, fine particles of hot crushed stone, in sufficient

quantity to completely cover the surface of the pavement. These stone chips shall be spread by means of a suitable stone-spreading machine, so designed as to provide a storage receptacle of at least five cubic feet capacity and to rapidly and uniformly cover the surface of the pavement with the desired quantity of stone. This spreading machine shall be provided with an adjustable attachment for regulating uniformly the quantity of stone spread at each operation. The hot stone chips shall be immediately and thoroughly rolled into the surface until it has become cool. The purpose of the flush-coat composition and fine particles of hot crushed stone are not only to fill any unevenness in the surface, but also to make the surface water-proof and gritty, thus providing a good foothold for horses.

d. In lieu of flush-coating of pure bitumen and screenings as above specified there may be used a "mineral flush coat" composed of a mixture of fine aggregate and bitulithic (bituminous) cement spread not to exceed one-half inch thickness over the bitulithic surface before the same is compressed and the two courses thoroughly rolled and blended together, the thickness of the bitulithic surface and mineral flush coat to be two inches after thorough compression with self-propelled road roller.

e. The bituminous composition or cement shall in each case be free from water, water-gas tar, or inferior process tars, and shall be especially refined to remove the light volatile oils and other matter susceptible to atmospheric influences.

f. Each layer of the work shall be kept as free as possible from dirt, so that it will unite with the succeeding layer.

Granite Pavement.

(16) *a. Description of Paving Blocks.*—Granite paving blocks shall be of medium-grained granite showing an even distribution of constituent minerals, of uniform quality and texture, without seams, scales or discolorations showing disintegration, free from an excess of mica or feldspar.

Blocks shall be rectangular in form and of the following dimensions, viz.: not less than eight nor more than twelve inches long, not less than three and one-half nor more than four and

one-half inches wide, not less than four and three-quarters nor more than five and one-quarter inches deep.

The blocks shall be so dressed that after laying a measurement of the individual joint will show not more than one-half inch in width at top and for a depth of one inch, nor more than one inch in width in any other part of the joint, provided that not more than one drill hole shall show on the side of the head and none on the end of the head of any block. The head of the block shall be so cut that it shall not have more than three-eighths inch depression from a straight edge laid in any direction across the head and held parallel to the general surface of the block.

(When a particularly smooth pavement is desired, the blocks should be so dressed that the head shall show a depression of but one-quarter of an inch instead of three-eighths, and lay with a three-eighths inch joint instead of one-half inch, as heretofore specified. The joints shall be filled with coarse sand to a depth of two inches and then thoroughly rammed. The remainder of the joints should then be filled with a bituminous material as specified for bituminous filler for brick pavements. This will produce a very smooth pavement and one as free from noise as possible.)

Care must be exercised in handling the blocks so that the edges and corners shall not be chipped or broken, as blocks otherwise acceptable may be rejected on account of spawling.

Over special constructions, the blocks may be of dimensions other than above specified when approved by the Engineer.

The stone from each quarry shall be piled and laid separately in different sections of the work, and in no case shall the stones from different quarries be mixed.

b. On the concrete foundation hereinbefore described shall be laid a bed of clean, coarse, dry sand the depth of one inch. Upon this sand bed the blocks shall be laid at right angles to the line of the street, and in a straight line from curb to curb, except in special cases when they shall be laid at such an angle as may be directed by the Engineer, who is also to determine the grade and crown to which the blocks must conform. Each course shall be of uniform width and depth, and so laid that all longitudinal joints shall be broken by a lap of at least three inches; the stone blocks shall not be laid more than twenty-five feet in

advance of the ramming. No blocks or other material must be thrown or deposited in such a manner as to displace the blocks on the face of the work, and no carting must be done within twenty-five feet of it.

c. When the pavement is to be laid with grouted joints the blocks shall be stiffened by sprinkling screened pea gravel running from one-eighth inch to three-eighths inch in size over the surface, which shall be swept into the joints with a wire broom to a depth of two inches. The blocks shall than be rammed ,to a uniform bearing true to the established grade and crown with a uniform surface; after the first ramming the blocks may be brought to a uniform surface by rolling with a steam roller weighing not less than five tons. All stones which settle below the grade line shall be raised or taken up by the person ramming, and reset with sufficient sand beneath and again rammed until they are brought to a uniform surface and unyielding bed. Any blocks which are broken by ramming must be replaced by other blocks. Before the pouring of the cement grout hereinafter provided for, the joints between the paving blocks must be cleaned out to a depth of three inches from the top, unless such a small amount of gravel has been left in the joints as not to interfere with the penetration of the grout to the bottom of the stone blocks. There shall then be immediately poured into the joints, pouring from the center to the sides, the cement grout as hereinafter described until the joints and the voids in the gravel between the paving blocks are full and will take no more and are filled flush with the top of the blocks. This pouring shall be done with special appliances, the design of which shall be approved by the City Engineer.

The grout shall be made of equal parts of Portland cement and clean, fine sand mixed with clear water to a fluid consistency so that the grout will penetrate to the bottom of the paving stones. The grouted joints shall be maintained flush with the top of the paving stones until the grout has set. After the grouting is completed the street shall be kept closed and no carting or traffic allowed until at least seven days have elapsed on any portion of the street grouted, and the face of the pavement shall be kept moist if the condition of the weather requires this precaution. The Contractor shall erect sufficient and well-constructed barricades and furnish watchmen at all times, if the same

shall be necessary to insure that this precaution in regard to the prevention of traffic or carting is complied with.

d. When the pavement is to be laid with tar and gravel joints the paving pitch to be used in filling the joints between and around the paving blocks and bridge stones shall conform to the following requirements:

It shall have a specific gravity between 1.23 and 1.33 at 60 degrees F.

It shall have a melting-point between 120 and 130 degrees F.

It shall contain between 20 and 30 per cent of free carbon.

When the pavement has been laid on the sand cushion the blocks shall be covered with a clean, hard and dry gravel, which shall have been artificially heated and dried in proper appliances, placed in close proximity to the work, the gravel to be brushed in until all the joints are filled therewith to within three inches of the top. The gravel must be entirely free from sand or dirt and must have passed through a sieve of three-eighths inch mesh and been retained by a one-quarter inch mesh. The blocks must then be thoroughly rammed and the ramming repeated until thay are brought to an unyielding bearing with a uniform surface, true to the given grade and crown. No ramming shall be done within twenty feet of the face of the work that is being laid.

The boiling paving pitch, heated to a temperature of 300 degees Fahrenheit, and of the composition hereinbefore described, shall then be poured into the joints until the same are full, and remain full to the top of the gravel. Hot gravel shall than be poured along the joints until they are full flush with the top of the blocks, when they shall again be poured with the paving pitch till all voids are completely filled. The appliances for heating paving pitch shall be sufficient in number and of such efficiency as will permit the pourers to closely follow the back rammers and all joints of the finally rammed pavement shall have been filled with paving pitch as above noted, before the cessation of the work for the day or any other cause.

e. Crosswalk flagstones shall be of the best quality of stone, similar to the paving-blocks, with smooth surface and parallel faces. Each stone shall be eighteen inches wide, six inches thick and not less than three feet long, with the ends cut to form a diagonal joint, varying from a right angle by six inches in the width of the stone. The end joints between flagstones shall not

exceed one-quarter inch for the full depth, and the sides shall be dressed square to the full depth. They shall be accurately fitted by an expert stonecutter to curbstones, gutterstones, street railway rails, surface sewers, manholes, or gates, and the stones where so fitted shall be carefully dressed, so that the face shall not have a depression of more than one-quarter inch from a right angle to the top of the stone. The joints shall be filled in the same manner and with the same material as are the paving-blocks.

Medina Sandstone Pavement.

(17) *a*. Paving blocks shall consist of the best quality of Medina sandstone free from quarry checks or cracks, and shall be quarried from fine-grain live rock, showing a straight and even fracture. The material shall be of uniform quality and texture, free from seams or lines of clay or other substances which, in the opinion of the City Engineer, will be injurious to its use as paving material.

Blocks shall measure not less than three nor more than six inches thick, and not less than six nor more than six and one-half inches deep, and from seven to twelve inches in length. Stones to have parallel sides and ends, and right-angle joints. All roughness in joints of stone to be broken off, so that when set in place they shall have tight joints for a distance of at least two and one-half inches from the top down. The top to have a smooth, even surface, with no projection or depression exceeding one-quarter inch.

When approved by the City Engineer, paving blocks of the following dimensions may be used:

Three to five inches in width; five inches in depth with an allowable variation of one-quarter inch more or less in said depth and seven to twelve inches in length.

Paving blocks, as here referred to, shall be understood to mean blocks of Medina sandstone, prepared in the usual manner for dressed-block paving by nicking and breaking the stones from larger blocks, as is done at the quarries where such blocks are usually prepared, and not made by redressing or selecting from common stone paving material.

The stones will be carefully inspected after they are brought on the line of the work, and all the blocks which, in quality and dimensions do not conform strictly to these specifications, will

be rejected, and must be immediately removed from the line of the work. The Contractor will be required to furnish such laborers as may be necessary to aid the inspector in the examination and the culling of the blocks.

Over vaults, around sewer or subway manhole frames, and in such other places as the City Engineer may deem proper, the Contractor shall use for the pavement, stone blocks and stone of such different dimensions and concrete foundations of such thickness as the said City Engineer shall direct.

b. On the concrete foundation shall be laid a bed of clean, sharp sand, perfectly free from moisture (made so by artificial heat if deemed necessary) not less than one inch thick, to the depth necessary to bring the pavement and crosswalks to the proper grade when thoroughly rammed.

Upon this bed of sand, the stone blocks and crosswalks must be laid. The stone blocks are to be laid in courses at right angles with the line of the street, except in intersections of streets, where the courses shall be laid diagonally, and except in special cases, when they shall be laid at such angle, with such crown and at such grade as the City Engineer may direct. Each course of blocks shall be of uniform width and depth, and shall be gauged and selected for the pavers on the sidewalks, and so laid that all longitudinal joints or end joints shall be close joints and shall be broken by a lap of at least three inches, and that joints between courses shall be not more than one-half inch in width. The blocks shall then be thoroughly rammed by courses at least three times by a rammer weighing not less than eighty pounds—no iron of any kind being allowed on its lower face to come in contact with the paving, and until brought to an unyielding bearing, with a uniform surface, true to the roadway on the established grade. The surface of the pavement thus completed must be even and smooth throughout and moulded to conform to the wells of the surface sewers, street and alley intersections, drainage details and the grade lines established by the City Engineer. During the final ramming the pavement shall be tested with a straight-edge and templet, and any unevenness must be taken out and made true to the required grade, level and cross-section.

c. If a paving pitch filler is used, the joints shall be filled with clean, dry, hot gravel of proper size as herein specified, heated in pans especially provided for that purpose, and poured from

cans having small spouts and thoroughly settled in place with wire picks until the level of the gravel is at least two inches below the top of the pavement.

The gravel used between the blocks shall be of such size as will pass through a sieve having four meshes per square inch, and be retained on a sieve of sixty-four meshes per square inch, and must be screened when dry.

The work shall then be completed in the same manner and with a paving pitch similar to that described under "Granite Pavements."

d. If a Portland cement grout filler is used in the joints instead of a paving pitch, the work shall be continued in the same manner as described under "Granite Pavements." After the grouting has been completed the street must be closed to traffic for at least seven days.

e. Crosswalks shall be as described under "Granite Pavements."

Brick Pavements.

(18) *a.* All brick must be strictly No. 1 pavers of the sizes commercially known as "vitrified block," and "brick,"* the widths of which must not vary more than one-eighth of an inch. They must be thoroughly annealed, tough and durable, regular in size, shape, and evenly burned.

When broken, the brick shall show a dense, stone-like body, free from lime, air pockets, cracks or marked laminations. Kiln marks must not exceed three-sixteenths of an inch, and one edge at least shall show but slight kiln marks. All brick so distorted in burning as to lay unevenly in the pavement shall be rejected.

The standard size of brick shall be two and one-half inches in width, four inches in depth and eight and one-half inches in length; and the standard size of block three and one-half inches in width, four inches in depth, and eight and one-half inches in length. They shall not vary from these dimensions to exceed one-eighth of an inch in width and depth, and not more than one-half inch in length. If the edges of the brick are rounded, the radius shall not exceed three-sixteenths of an inch.

All brick shall be subject to thorough inspection before and

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* Whenever the word "brick" is used in these specifications it is intended to refer to either brick or block, whichever may be used.

after laying and rolling, and all rejected material shall be immediately removed from the street.

The brick shall be hauled, carefully unloaded by hand, and neatly piled on the walks or outside of the curbs before the grading is finished, and in laying shall be carried from there to the pavement.

b. The brick shall not lose of their weight more than   per cent after being tested in the manner recommended by the National Paving Brick Manufacturers' Association

c. Over the concrete foundation, which must be thoroughly cleaned, shall be spread to a uniform depth of one and one-half inches (after rolling), a cushion of clean, sharp sand, free from loam or foreign matter. The sand must pass a one-quarter inch screen.

The cushion shall be carefully shaped to a true cross-section of the roadway by means of a proper template.

Before shaping the cushion a one-half inch strip shall be laid on the curb, and guide timbers, or rail, and the template drawn over the same, after which the one-half inch strip shall be re-removed, the cushion slightly moistened and rolled over its entire surface with a hand roller. The roller shall be not less than thirty-six inches in diameter, twenty-four inches in width, and shall weigh not less than 10 pounds per inch in width, and have a handle twelve feet in length. After rolling, the template shall be drawn over the curb and guide timbers or rail, to complete the cushion. The cushion shall be prepared at least fifty feet in advance of the brick laying.

The brick shall be laid in straight lines on edge, at right angles to the curb. At intersections they shall be laid as directed. Brick must be placed close together, both ends and sides, breaking joints at least three inches. At every fourth course the brick shall be driven together to secure tight joints and straight courses, and all thick brick shall be removed. Brick shall be used with the best side up.

When any section shall contain more than ten per cent of culls, the brick shall be taken up and the cushion adjusted. Brick shall be laid from curb to curb, or car track to curb.

No bats or broken brick shall be used except at curbs or at street car tracks. Batting for closures shall immediately follow the laying.

Joints shall be cut square with the top and sides of the brick. All joints must be kept clean and open to the bottom until filled as specified.

d. After the brick in the pavement have been passed for rolling and the surface swept clean, the pavement shall be rolled with a roller weighing not less than three nor more than five tons, in the following manner: The brick next the curb shall be tamped with a hard-wood tamper, to the proper grade. The rolling shall then commence near the curb at a very slow pace, and continue back and forth toward the center, until the center of the street is reached; then, passing to the opposite curb, it shall be repeated in the same manner to the center of the street. After this first passing of the roller the pace may be quickened and the rolling continued until each brick is firmly embedded in the sand cushion. The pavement shall than be rolled transversely at an angle of forty-five degrees from curb to curb, repeating the rolling in the opposite forty-five degree direction. Before and after this transverse rolling has taken place, all broken or injured brick must be taken up, and replaced with perfect ones. The substitute brick must be brought to the true surface by tamping.

After final rolling the pavement shall be tested with a ten-foot straight edge, laid parallel with the curb, and any depression exceeding one-quarter of an inch must be taken out. If necessary, the pavement shall be again rolled.

e. Expansion joints shall be placed parallel with and at each of the curb lines, and shall be one and one-half inches in width. The joints shall be made by placing together on edge, parallel with the curb, two wedge-shaped strips six inches in width, and dressed on two faces. The strip next to the curb shall be one inch wide on top, beveled to a thickness of one-half inch at the bottom, and the strip next to the brick shall be of the same dimensions and placed in a reverse position. The brick shall be laid lightly against said strips. Soon after the pavement has been grouted, and the cement filler has set, and the pavement is in all other respects finished, the strips shall be removed, the joints thoroughly cleaned out, and immediately completely filled with a bituminous filler composed of a material which, when penetrated by a No. 2 needle under a weight of 200 grams for one minute at a temperature of 32 degrees F., will have a penetration of not less than 20, and when penetrated with a No. 2 needle

under 50 grams for five seconds in a temperature of 115 degrees F., will not have a penetration of over 100.

f. When a cement grout filler is used it shall be mixed and applied in practically the same manner as specified in the granite specifications.

g. When a coal-tar paving pitch filler is used the joints or spaces between the bricks, and those between the bricks and the curb, railroad tracks, around manholes, etc., shall be filled with coal-tar paving pitch, which shall comply with the following requirements:

When in place in the pavement, it shall be of such character that it will adhere firmly to the paving brick and to the curb, and shall be sufficiently plastic to allow for the contraction and expansion in the pavement without developing cracks in the joints. It shall be proof against action by water and all acids and alkalis to which the pavement may be exposed.

The free carbon shall not be less than 25 per cent nor more than 40 per cent. The specific gravity shall not be less than 1.23 nor more than 1.30 at 60 degrees F.

It shall have a melting-point varying not more than 5 degrees from 135 degrees F., determined by the cube method as follows:

A clean-shaped one-half inch cube of the pitch is to be formed in the mold and suspended in the beaker so that the bottom of the pitch to be tested is one inch above the bottom of the beaker. The pitch is to remain for five minutes in water of a temperature of 60 degrees F. before heat is applied. Heat is to be applied in such a manner that the temperature of the water is raised 9 degrees F. each minute. The temperature recorded by the thermometer at the instant the pitch touches the bottom of the beaker to be considered the melting-point. The filler shall be such that it retain its consistency under extreme temperature.

Methods of Use.—The filler shall be heated and poured into the joints to the full depth thereof, at a temperature of not less than 300 degrees F., nor greater than 350 degrees F. All joints shall be completely filled at the top. The top dressing of sand shall be spread over the pavement immediately after the filler is applied and while it is still soft. In cold weather the sand shall be heated so as to readily bond with the pitch. Extra care shall be used at the gutters and around catch basins, etc., to effectually prevent the leakage of water into the sub-roadway.

Wood Block.

(19) *a.* The material to be treated shall be wood blocks of Southern long-leaf yellow pine, and is to be subject to inspection at the works in the stick before being sawed into blocks.

The blocks shall be cut from what is known as southern yellow pine, well manufactured, full size, saw-butted, all square edged, and shall be free from the following defects: unsound, loose and hollow knots, worm holes and knot holes through shakes and round shakes that show on the surface.

The paving blocks cut from the lumber above specified shall be well manufactured, truly rectangular and of uniform dimensions and their depth parallel to the fibre shall be four inches; their length shall be eight inches, and their width shall be three inches. No variations of the above dimensions to exceed one-sixteenth of an inch in depth, one-eighth in width or one inch in length.

b. The blocks shall be so treated with an oil elsewhere described that they shall contain not less than twenty pounds per cubic foot.*

After treatment the blocks are to show such waterproof qualities that after being dried in an oven at a temperature of 100 degrees F. for a period of twenty-four hours, weighed and then immersed in clear water for a period of twenty-four hours and again weighed, the gain in weight is not to be more than 3½ per cent.

The oil with which the blocks are to be treated shall be a coal-tar product from which the water has been removed and which shall have a specific gravity of not less than 1.10 at 38 degrees centigrade.

When distilled in the manner hereinafter described, the oil shall lose not more than 35 per cent up to a temperature of 315 degrees centigrade. The distillate between 255 degrees centigrade and 315 degrees centigrade shall have a specific gravity not less than 1.02, the said specific gravity being taken at a temperature of 60 degrees centigrade.

One hundred grams of oil are weighed out into a glass retort, preferably made of Jena glass, having a capacity to bend of neck of 250 c.c. A condensing tube, air cooled, is attached to the retort

* On a heavy traffic street the treatment can be reduced to sixteen pounds per cubic foot.

of such length that the total distance from the tubulure to the end of the condensing tube shall be approximately 60 cm. The tubulure is fitted with a cork through which a nitrogen-filled thermometer registering to 400 degrees C. and about 40 cm. in length is inserted in such a manner that the bottom of the bulb shall be not less than one-half inch above the liquid at the time distillation commences. The first reading on the emergent stem of the thermometer shall be not less than 80 degrees and no correction is made for the emergent stem. The distillation is made in a place free from draughts and the retort is heated by the direct flame of an adjustable burner. The oil is warmed cautiously until any water that may be present is expelled. If water is present, the amount is reported separately, all results being calculated on a dry-oil basis. The flame is then regulated in such a manner that the rate of distillation shall continuously be not slower than one drop per second, and not faster than two drops per second. The distillates are collected in weighed Erlenmeyer flasks. The specific gravity of the fraction boiling from 255–315 degrees C. is determined by means of a specific gravity bottle having a capacity of about 10 c.c. The oil previously warmed is poured into the bottle, which is then placed in a thermostat kept at 60 degrees C. for one-half hour. The stopper is then inserted, the excess of oil wiped off and after cooling the weight is obtained. This weight is compared with the weight of water at 60 degrees C. which the same bottle contains.

c. During the progress of manufacture and treatment of paving blocks under this contract the Engineer may designate a representative who shall at all such times have full facilities afforded him by the Contractor to inspect the timber, materials and methods used in the manufacture and treatment of the blocks, and any or all timber, materials or finished blocks not strictly in accordance with the requirements of these specifications may be rejected by the Engineer on filing written notice with the Contractor.

Blocks will also be carefully inspected by the Engineer or his representative after they are delivered on the street, and all deliveries which in quality, character and dimensions do not conform strictly to the contract requirements will be rejected and must be immediately removed from the line of the work by the Contractor.

d. Upon the surface of the concrete foundation, prepared

as heretofore described, shall be spread a bed of cement mortar one-half inch in thickness, which shall bring the thickness of the complete foundation up to six inches. This mortar surface shall be composed of a slow-setting Portland cement and clean, sharp sand, entirely free from pebbles over one-eighth inch in diameter, and mixed in the proportion of one part of cement and two parts of sand, until the sand and cement show an evenly blended color. This shall then be mixed with the minimum amount of water required to make a mortar of very stiff consistency. This mortar bed shall be struck to a true surface exactly parallel to the tip finished pavement and four inches below it, in the following manner:

Upon this mortar surface the blocks shall be immediately laid with loose joints and uniform top surface, but no joints shall be more than one-eighth inch in width. The blocks shall be laid by the pavers standing upon the blocks already laid, and not upon the bed of mortar. The blocks shall be laid at right angles with the line of the street, except at street intersections, where they shall be laid diagonally, and with such crown as the Engineer may direct; and in such a manner that all longitudinal joints shall be broken by a lap of four inches. When thus laid the blocks shall be immediately covered with clean, fine sand, entirely free from any loam or earthy matter, perfectly dry, and screened through a sieve or screen having not less than ten meshes to the inch. This sand shall be swept over the surface until all joints are filled, when the surplus sand, if any, shall be swept off and the pavement rolled with a five-ton steam-roller, until the surface is uniform and the blocks are firmly bedded. The rolling must be done as expeditiously as possible so as not to interfere with the setting of the mortar bed. After the rolling has been completed the pavement shall be covered with sand. When traffic is allowed on the pavement and settles the sand in the joints they shall be swept full until they remain so permanently. Any surplus remaining shall then be removed.

After the blocks are laid and sanded, however, the pavement must be protected from all vehicular traffic for a period of forty-eight hours.

e. If at any time during the guarantee period the preservative shall exude from the blocks to such an extent as to form a nuisance, the surface of the pavement where the exudation takes place shall

be sprinkled with fine sand to such extent as to absorb the exuding matter. This sand shall be removed by the Contractor upon notification by the City Engineer.

(20) In case any curb, flag, paving, trees, fence or barrier, or other material along the line of the work become broken or injured by the Contractor or his agents during the progress of the work, they are, if required, to be removed, and others equally as good placed in their stead, at the expense of said Contractor, and to the satisfaction of the Engineer.

(21) Should any sewer manhole or catch-basin heads require raising or lowering to conform with the proper grade, such heads shall be so raised or lowered by the Contractor at his expense. Manholes or other surface work of any corporation will be adjusted by the company or corporation owning them upon notice from the City Engineer.

(22) *Clearing Up.*—All surplus materials, earth, sand, rubbish, and stones, except such stones as shall be retained by the order of the Engineer, are to be removed from the line of the work, block by block, as rapidly as the work progresses. Unless this be done by the Contractor within twenty-four hours after being notified so to do, to the satisfaction of the City Engineer, the same shall be removed by said Engineer, and the amount of the expense thereof shall be deducted out of any moneys due or to grow due to the party of the second part under this agreement.

(23) All loss or damage arising out of the nature of the work to be done under this agreement, or from any unforeseen obstructions or difficulties which may be encountered in the prosecution of the same, or from the action of the elements, or from incumbrances on the line of the work, shall be sustained by the said Contractor.

In case any injury is done along the line of the work in consequence of any act or omission on the part of the Contractor or his employees or agents in carrying out any of the provisions or requirements of this contract, the Contractor shall make such repairs as are necessary in consequence thereof, at his own expense and to the satisfaction of the City Engineer; and in case of failure on the part of the Contractor to promptly make such repairs, they may be made by the City Engineer, and the expense thereof shall

be deducted out of any moneys to grow due or to be retained from the party of the second part under this contract.

(24) The prosecution of the work shall be suspended at such times and for such periods as the City Engineer may from time to time determine; no claim or demand shall be made by the Contractor for such damages by reason of such suspensions in the work, but the period of such suspensions to be determined in writing by the said Engineer will be excluded in computing the time hereinafter limited for the completion of the work. During such suspension all materials delivered upon but not placed in the work shall be neatly piled or removed so as not to obstruct public travel.

(25) Whenever the word "Contractor" or a pronoun in place of it is used in this contract, the same shall be considered as referring to and meaning the party or parties signing the contract or his authorized agent.

(26) The work shall be commenced on such day and at such point or points as the City Engineer shall designate, and progress therewith so as to be fully completed in accordance with this agreement, on or before the expiration of ——— working days.

(27) *Damages for Non-completion.*—If the Contractor shall fail to complete his contract within the time specified, the City Engineer shall make a careful estimate of the value of the work to be performed at the expiration of the contract time. When the work shall be finally complete the said Engineer shall deduct from the final estimate, as liquidated damages, an amount equal to one-half of one per cent of the value of such uncompleted work obtained as above for each working day in excess of the time specified in the contract, provided that the amount charged shall not be less than the actual increased cost of inspection.

(28) If at any time any overseer or workman employed by the Contractor shall be declared by the Engineer to be unfaithful or incompetent, the Contractor, on receiving written notice, shall forthwith dismiss such person, and shall not again employ him on any part of the work.

(29) When each section of the street has been completed, travel is to be allowed thereon, if required by the Engineer; and at the time of completion of the entire work, and before the final pay-

ment, the Contractor will be required to make good at every point any defect which is the result of non-compliance with any of the provisions of this contract.

(30) The said party of the second part hereby further agrees that he will obey and conform to all ordinances of the city now in force, or that may be in force, during the progress of such work.

(31) If at any time the City Engineer shall be of the opinion, and shall so certify in writing, that the said work or any part thereof is unnecessarily delayed, or that the said Contractor is wilfully violating any of the conditions or covenants of this contract, or is executing the same in bad faith, or if the said work be not fully completed within the time named in this contract for its completion, he shall have the power to notify the aforesaid Contractor to discontinue all work, or any part thereof under this contract, by a written notice to be served upon the Contractor, either personally or by leaving said notice at his residence or with his agent in charge of the work, and thereupon the said Contractor shall discontinue said work or such part thereof. The City Engineer shall thereupon have the power to place such and so many persons as he may deem advisable, by Contract or otherwise, to work at and complete the work therein described, or such part thereof, and to use such materials as he may find on the line of said work, and to procure other materials for the completion of the same, and to charge the expense of said labor and materials to the aforesaid Contractor, and the expense so charged shall be deducted and paid by the party of the first part out of such moneys as may be then due, or may at any time thereafter grow due, to the said Contractor under and by virtue of this agreement, or any part thereof; and in case such expense is less than the amount which would have been payable under this contract if the same had been completed by said Contractor, he shall forfeit all claim to the difference; and in case such expense shall exceed the said sum he shall pay the amount of such excess to the party of the first part.

(32) *Guarantee.*—Asphalt and other bituminous pavements shall be kept in repair, as specified herein, at the expense of the Contractor for the term of five years, and all other pavements for the term of twelve months, from the date of the provisional

acceptance of the work, at which time it is to be turned over to the city according to the provisions of Section 36,—provided, however, that should the date of final acceptance fall between December 1st and March 31st, the City Engineer shall have the right to postone said final acceptance until the weather will permit an examination and necessary repairs to be made.

(33) During the performance of said work the Contractor shall place proper guards upon and around the same for the prevention of accidents, and at night shall put up and keep suitable and sufficient lights, and shall indemnify and save harmless the party of the first part against and from all suits and actions, of every name and description, brought against it, and all costs and damages to which it may be put for or on account or by reason of any injury or alleged injury to the person or property of another, resulting from negligence or carelessness in the performance of the work, or in guarding the same, or from any improper materials used in its prosecution, or by or on account of any act or omission of the said Contractor; and the whole or so much of the moneys due the said Contractor, under and by virtue of this agreement, as shall or may be considered necessary by the City Engineer, shall be retained by the proper city officials until all such suits or claims for damages as aforesaid shall have been settled, and evidence to that effect furnished to the satisfaction of the said Engineer.

(34) On a street paved with asphalt if, at any time during the period of guarantee, the work or any part thereof, or any depressions, bunches, or cracks, shall, in the opinion of the City Engineer, require repairs or sanding, as provided for in Section 13, paragraph *k*, and the Engineer shall notify the Contractor to make the repairs or do the sanding as required, by a written notice to be served on the Contractor either personally or by leaving said notice at his residence or with his agent in charge of the work, the said Contractor shall immediately commence and complete the same to the satisfaction of the said Commissioner; and in case of failure or neglect on his part so to do within forty-eight hours from the date of the service of the aforesaid notice, then the said Engineer shall have the right to purchase such materials as he shall deem necessary, and to employ such person or persons as he shall deem proper, and to undertake and complete said repairs or sanding, and

to charge the expense thereof to the said Contractor; and the said Contractor hereby stipulates and agrees to pay all such expense to which the said Engineer may have been put by reason of the neglect of the said Contractor to make such repairs or to do the sanding as aforesaid.

(35) The Contractor further agrees that he will during the same period lay and restore the pavement over all openings made by corporations or plumbers for making new service-connections or repairing, renewing, or removing the same, and over all trenches made for carrying sewers, water- or gas-pipes or any other subsurface pipes or conduits, for the building or laying of which permits may be issued by the proper authorities for the contract price per square yard for all openings whatever, the Contractor or corporation making such opening or trench having taken such precautions to prevent settlement of the filling over the same as are deemed necessary by the said Engineer.

All materials to be of the same quality and mixed in the same manner as specified in this contract.

The Contractor further agrees not to demand additional or further payment on account of repairing any injured or sunken pavement laid over the repairs above described.

(36) Just previous to the expiration of the guarantee period on asphalt or other bituminous pavements the entire work shall be inspected, and any bunches, depressions, or unevenness in the surface of the pavement that shall show a variation of three-eighths of an inch under a four-foot straight-edge or template, or any crack wider than one-fourth of an inch, or any portion of the pavement having a thickness of less than one and one-half inches shall be immediately repaired upon the order of the City Engineer, by the heater process or by removing the entire pavement from the concrete, and replacing it in the same manner as when originally laid;—provided, that when more than fifty per cent of the surface of any one block requires repairing according to the above conditions, the entire block shall be taken up and relaid. Whenever any defects are caused by the failure of the concrete or the settlement of the roadway from any source, the entire pavement, including foundation, shall be taken up and relaid in accordance with the specifications.

Just previous to the expiration of the guarantee period on stone, brick or wood pavements the entire work shall be inspected, and any defects caused by inferior material or defective work, or settlements from any cause, shall be immediately repaired on the written order of the City Engineer and to his satisfaction.

Should the Contractor for any kind of pavement fail to make the necessary repairs within six days after being served with the above order, or to perform the work in a satisfactory manner, the City Engineer shall have the same done and charge the cost thereof to the reserve fund held for that purpose. After all repairs have been satisfactorily made, the City Engineer will issue his certificate to that effect.

(37) *Payments.*—When the amount of the contract is more than $5000, on or about the first day of each month a payment will be made to the Contractor of eighty per cent of the value of the work performed during the previous month upon the issuance of the certificate of the City Engineer;—provided that no partial payment will be made after the expiration of the time for the completion of the contract.

When the work has been entirely completed, and such completion certified to by the City Engineer, the entire amount due under the contract shall be paid to the Contractor less any payments previously made and any amounts rightly retained under the provisions of these specifications.

On all work guaranteed for five years ten per cent of the amount of the contract price shall be retained till the end of the guarantee period; but the contractor will be allowed to deposit city bonds with the financial agent of the city to the amount of the reserve due, when the entire balance will be paid. During the guarantee period he will be allowed to draw all interest due upon the bonds, and upon the final acceptance of the work, and the Engineer's certificate to that effect, the entire amount will be returned to the Contractor, less any amount paid out for repairs.

On work guaranteed for twelve months a sum of ten cents per square yard for stone, brick or wood pavements, shall be retained until the final acceptance, when the said retained sum, less any amount expended for necessary repairs, will be paid.

CHAPTER XIV.

THE CONSTRUCTION OF STREET-CAR TRACKS IN PAVED STREETS AND ROADWAYS.

The problem of how to construct street-car tracks in the best manner in paved streets has been troubling engineers in charge of pavement construction for many years. In the early days of street-railways, when the streets were paved with cobblestones and when street-cars were small and drawn by horses at a speed of five or six miles an hour, this question was not so important. But in the present time of asphalt and other improved pavements, of rubber tires, bicycles and automobiles, and with cars weighing from 10½ to 12 tons propelled by electricity along our streets at a speed of from eight to fifteen miles per hour, the importance of good and smooth track-construction, both to the general public and to the street-car company, can hardly be overestimated.

There is no doubt that the street-car track is detrimental to any pavement, but it is a necessary evil, for it is well recognized at the present time that no one thing tends to develop and build up a city as does a good system of street-cars.

The problem of the construction of street-car tracks is very different from that of the ordinary steam-railways. The steam-cars run on their own right of way, making stops only at long intervals, and the tracks can be constructed in such a manner as will give the best results as regards economy of construction and maintenance, with no regard for the wishes of others, except at street or road crossings.

Street-cars, however, run through public highways which are being used constantly by vehicles, and crossed often by pedestrians,

and their construction must be such as will not only accommodate their own cars, but also interfere as little as possible with the ordinary vehicular traffic of the street.

It must be remembered, however, in this connection that there are two travelling publics, the one in the cars and the other using private vehicles, and while the former uses the vehicles of the corporations, operated in a public thoroughfare, any action which tends to discommode or interfere unnecessarily with the action of the cars must discommode to a great extent a very large proportion of the travelling public. Probably 40 per cent of all the business men in the average American city of more than 100,000 inhabitants depend more or less upon the street-cars for their convenience every day.

The authorities of street-railways, and the cities in which they are operated, generally differ considerably in their ideas of what is the proper construction for the tracks. The street-car companies are interested only to perform their work economically. A construction that will allow their rolling-stock to be operated with the least amount of wear and tear and will cost the least for original construction, as well as maintenance, is what they desire. On the other hand, the city authorities are not interested to any great extent, either in the cost of construction or maintenance. They wish a construction that can be carried out with little obstruction to the general travel of the street, will require but little interference with the pavement for maintenance and repairs, and present little obstruction to the general traffic.

In early track-construction the railway companies sometimes sought to lay a rail that would be very obstructive to travel. When a track is such that vehicles seek it in preference to the street, the operation of the street-cars is interfered with, and the companies seek every means to prevent this.

With the rough stone pavements of twenty-five years ago, the special form of the rail added very little to the general roughness of the street, but railway companies must recognize at the present time that smooth and improved pavements have come to stay, and that they must adopt a method of track construction that will conform to these pavements.

The ideal construction seems to be one in which the track is a part of the pavement itself, and not a separate and definite part of the work, and the track and pavement should be studied together as one whole. The time of probable renewal of each part should be taken into consideration, and the design of each made so as best to accommodate these renewals. This, however, is not very often practicable, from the fact that it very seldom happens that a pavement and a railway-track are constructed at the same time, so that certain modifications or concessions can be agreed upon and the best results for both obtained.

The question should be taken up by the railway and city authorities conjointly, as if both were owned and were to be operated by one interest; and after the details which would be best under this arrangement were determined upon, general modifications could be made if desired, so that the interest of either party would not suffer.

Street-railway companies, having operated in public highways for so long a time, with an inexpensive construction determined upon by themselves, find it very hard at times to meet the requirements of modern pavements and the present city officials, but they soon find that it is better economy as well as better policy to adopt a construction that will be both durable and satisfactory to the municipal authorities.

The question as to the proper remuneration to be made to municipalities for the use of its highways for the operation of street-cars has never been definitely settled. In some cities it is arrived at by the company's paying a certain amount to the city, sometimes based upon its receipts, the number of passengers carried, or sometimes a lump sum determined upon in advance.

In some cities, also, the cost of paving is settled in much the same way; but, as a rule, the actual amount of the street to be cared for by the railway company is defined either in its charter or by special legislation. No attempt will be made in this connection to treat the question of value from the franchise standpoint, but simply with reference to the care of the pavement.

In 1854 an Act was passed by the Massachusetts Legislature incorporating the Dorchester Avenue Railway Co. and requiring it

to keep in repair the whole of the bed of any road in the town of Dorchester in which it might lay tracks. In the following year, however, this Act was amended by a repeal of this clause and the substitution of a provision requiring only that part of the road occupied by the tracks to be kept in repair, and defining that portion "to be the space between the rails and so much on each side thereof as shall be within a perpendicular let fall from the extreme width of any car or carriage used thereon, being the space from which public travel is excluded during the passing of said car or carriage."

In Baltimore, Md., the street-car companies pave and keep in repair the space between their tracks, and 2 feet on each side.

In Buffalo, N. Y., different conditions exist in regard to the paving requirements by the different companies, but in general the maintenance of the street between the tracks and 2 feet outside is required, the pavement to be of a kind specified by the city.

Although in some locations no paving at all is required from the street-car companies, in New York a bill was passed in 1895 which provided that one-fourth of the cost of repaving any street in Brooklyn in which was operated a street-railway should be assessed against the company owning such track. A great many streets were paved under this law, but at the present time no tax has been collected from the street-car companies. This question, however, will probably be settled by a general New York statute which will be referred to later on.

In an ordinance passed in February, 1907, by the City Council of Chicago special provisions were made for the construction of street-car tracks in that city. It was provided that the tracks should be laid with modern improved rails of the grooved type, weighing not less than 129 pounds per yard, and that the rails should be laid upon concrete beams, wooden ties, steel ties, cast-iron chairs, or some other form of first class modern approved street-railway track construction; the foundation to be of concrete, crushed stone or other ballast material which in the judgment of the Board of Super-

vising Engineers should best suit the conditions of soil and drainage.

As regards the maintenance of the space in the streets occupied by the tracks it provided that the company should fill, grade, pave, keep in repair, sweep, sprinkle and keep clean and free from snow 8 feet in width of all streets and public ways, or portions thereof, occupied by it with a single-track railway, and 16 feet in width of all streets and public ways, or portions thereof, occupied by it with a double-track railway.

It also provided that when the city paved the street in which car tracks were located with an improved pavement, the company should pave its area as given above with a granite block pavement, which was described in detail, making a modern granite pavement. It was provided, however, that in any ordinance ordering the paving of streets the company could be required to pave its area with the same material specified for the remainder of the street.

Detroit, Mich., has what are known as 3-cent and 5-cent car lines. In streets where the former lines are operated the city paves the entire area, but in streets where the 5-cent lines are operated the street-car company paves and maintains its area.

In Indianapolis, Ind., a readjustment of the terms of the original franchise was made in 1878, when a provision requiring the road to repave between its tracks was changed so as to read "repair between its tracks." On account of this action there is considerable feeling between the taxpayers and the railway company.

In New York City it is held that the different companies are bound by Chapter 676 in Laws of 1892, a portion of which reads as follows:

"Every street-railroad, so long as it shall continue to use any of its tracks in any street, avenue, or public place in any city or village, shall pave and keep in permanent repair that portion of such street, avenue, or public place between its tracks or rails of its tracks, and two feet in width outside of its tracks, under the supervision of the proper local authorities, and

whenever required by them to do so, and in such manner as they may prescribe. In the case of neglect of any corporation to make these pavements or repairs after the expiration of thirty days' notice to do so, the local authorities may make same at the expense of such corporation."

The street-car companies, however, have not always lived up to this requirement, and it was stated in a paper read before the American Society of Civil Engineers in December, 1896, that bills aggregating more than $700,000 had accumulated against surface railways on Manhattan Island from 1889 to 1895 inclusive.

The street-car companies in the city of Philadelphia have probably expended more money for pavements in city streets than any other city in the world. In 1892 the street-railways changed their power from horses to electricity, and an agreement was entered into between the companies and the city authorities by which the roads agreed to pave and maintain the streets through which they operated, from curb to curb. The streets of Philadelphia being so narrow that in most cases only one track is operated for each street, a large amount of street mileage is occupied by the street-car companies. It is said that on January 1, 1898, there had been expended by the different companies for street pavement since 1892, when the above agreement was entered into, a sum amounting to about $12,000,000.

More recently an arrangement has been made with the railroad company by which it pays the city a sum of $500,000 annually to fulfill its pavement obligations.

In Rochester, N. Y., the railway company accepted the provisions of the statute previously referred to as far as repairs to the pavement were concerned, but it did not admit its obligation in regard to new pavements. In a test case brought to settle this point, the two following questions were asked:

"Are the abutting owners on Lyell Avenue liable for the cost of constructing a new pavement between the tracks, the rails of the tracks, and 2 feet in width outside of the tracks of the Rochester Railway Co.? Second: Is the duty of the Common Council of the city of Rochester to request the railway company to construct a pavement between its tracks, the rails of its tracks, and

for 2 feet outside thereof, on Lyell Avenue, before the city constructs such pavement, mandatory?"

The court decided the first question in the negative, and the second in the affirmative. The railway company not being a party to the suit, the decision was not accepted by them as final, and the case is being carried through the courts at the present time in a different form. The city authorities, however, have carried out the work of paving the streets occupied by the railway company, and have made out the bills as if the law were in force.

In St. Louis, Mo., the companies are required to pave within the tracks and 12 inches outside of the rails, with a material approved by the Commissioner of Public Works.

In Toronto, Can., the street-car tracks are owned by the city, and in 1891 the exclusive privilege of operating them was granted to the Toronto Railway Co. In the agreement made between the city and the company it is required that the purchaser shall maintain the ties, stringers, rails, turnouts, curves, etc., in a state of thorough efficiency and to the satisfaction of the City Engineer, and shall remove, renew, or replace same as circumstances may require and as the City Engineer may direct. When a street upon which the tracks are now laid is to be paved in a permanent manner on concrete or other foundation, then the purchaser shall remove the present tracks and superstructure, and repave the same according to the best modern practice, by improved rails, points, and substructure of such description as may be determined upon by the City Engineer as most suitable for the purpose. In the event of the purchaser desiring to make any repairs or alterations to the ties, stringers, rails, turnouts, curves, etc., on paved streets, the purchaser shall repave the portion of the railway so torn up at his own expense.

When the purchaser desires, or is required, to change any existing tracks or substructure for the purpose of operating by electricity or other motive power approved by the City Engineer and confirmed by the Council, the city will lay down permanent pavement in conjunction therewith upon the track allowance as herein defined to be occupied by said new tracks and substructures. This at first applied only to existing main lines and thereafter to branch

lines or extensions to main lines and branches. Under the terms of the agreement the company pays the City Treasurer $1600 per annum per mile of double track and eight per cent of the gross receipts, and when the receipts exceed $1,000,000 ten per cent is to be paid.

In the city of Washington, D. C., the amount of pavement to be cared for by street-railway companies is provided for by an Act of Congress approved June 11, 1878. This requires that—

"When any street or avenue through which a street-railway runs shall be paved, such railway company shall bear all of the expense for that portion of the work lying between the exterior rails of the tracks of such roads and for a distance of 2 feet from the exterior to such track or tracks on each side thereof and of keeping same in repair, but the said railway company, having conformed to the grades established by the Commissioners, may use such cobblestones or Belgian blocks for paving their tracks or the spaces between their tracks as the Commissioners may direct."

Much the same conditions and requirements exist in European as in American cities in regard to the pavement between the tracks, although the street-car mileage is much less than in American cities of the same population.

The construction of railways in Great Britain is governed by the Tramways Act of 1870. As regards pavements, it provides that the companies shall repair and maintain the space between the tracks and 18 inches on each side. If not properly done it may, after seven days' notice, be done by the road authorities and charged to the company.

In Amsterdam, Holland, the street-car company is obliged to put the streets in good order after construction and to maintain them between the rails and 20 inches on each side, and where the street is not paved this same space is required to be paved by the company. In addition to this the street-car company pays the city the sum of $600,000 for general widening of streets, construction and paving of new roads, the building of new and changing and widening of old bridges, the filling and earthing over canals and laying sewer-pipes.

The city of Berlin, Germany, has a very elaborate and specific contract with the street-railway companies. The requirements for laying and maintaining pavements are entered into in great detail, but in the main compel the companies to lay a permanent pavement, whenever the remainder of the street is so paved, on the space occupied by the tracks and to a distance of 12 inches on both sides of each rail. They are also required to keep the pavement between their rails and 26 inches outside of the outer rails in good condition.

In Hamburg, Germany, a contract between the city and one of the largest of the railway companies requires the company for a period of twenty-five years from 1898 to pay the city in lieu of any paving or street-cleaning a charge of 1 pfennig ($\frac{1}{4}$ cent) per passenger carried for a cash fare and five per cent on commutation-tickets.

In Vienna, Austria, the street-car company is obliged to pave and maintain a space of $8\frac{1}{4}$ feet in width for each track.

The above gives a general idea of the requirements in a number of cities in this country and in Europe as regards the cost of keeping the portion of the streets occupied by street-car tracks well paved.

Location.

The location of the street-car tracks is important and should be and is generally under the direction of the city authorities. As a rule, it is better that they be located in the centre of the street, but in case any large tract of land adjacent to a street is occupied by parks, cemeteries, or other public grounds, it is often more convenient for the general public that the tracks be located on one side. This gives some space for general traffic and generally will accommodate that portion of the public using street-cars better, as, in the case of both cemeteries and parks, the majority of the passengers on that portion of the line will be on the side where the track is located and so be able to take the car without entering the street.

In country roads outside of villages it will be more satisfactory

to have the location on one side, as that will leave the centre of the road free for general travel. In such case the space between the tracks, in many instances, need not be paved, and where the roadway is not improved to any great width the track can often be laid outside of the improvement. In speaking on this point, in a paper before the American Society of Civil Engineers, read in December, 1896, Mr. James Owen says:

"On a 50-foot roadway a 20-foot driveway in the centre, the track on each side and within 9 feet of access to houses, gives good satisfaction, preserves the driveway, and lessens repairs.

"In a 60-foot roadway and 14-foot driveway outside the tracks, all the requirements are attained. In a roadway of less than 50 feet the tracks must of necessity be in the centre. Where only one track is laid on a country road the track should be on one side with the switches toward the centre.

"Whenever a track is laid in the centre of a country road it should always be paved with some material whether the road as well is improved or not."

In Beacon Street, Boston, the roadway is extremely wide, and parks are located in the centre, sodded with grass, and in many places set out with trees and ornamental shrubs. In many other streets in and near Boston the tracks are located on a strip given up wholly to them.

Canal Street, New Orleans, is 170 feet 6 inches wide, and the sidewalks are 18 feet in width. In the centre of the street is a space 60 feet wide, called "neutral strip," in which four lines of street-car tracks are laid. On each side of the "neutral strip" are carriage driveways 37 feet 3 inches wide. This street is paved with asphalt, the entire cost being borne by the city, including the "neutral strip," which is wholly occupied by railway companies.

The first charter for a street-railway company in Massachusetts was granted by the Legislature to the Metropolitan Railway Company of Boston in 1853, and about the same time the first street-railway track was laid on Fourth Avenue in New York City. A "rail-bus" was built and operated for a short time in the latter city by John Stephenson in 1832. The first horse-railroad was operated in January, 1858.

In Paris the first tramway was constructed in 1853, although

not very much developed during the first twenty years; while the first street-car lines in London and in Glasgow were constructed by Americans in 1860. These early companies were very crude in their operation and construction as compared with the present time. The first rail was practically a piece of flat iron spiked to a stringer with a groove in which the flange of the wheel ran; but as traffic increased a more substantial rail was required, and that shown in Fig. 33 was adopted. This was spiked to the stringer,

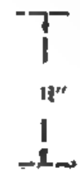


FIG. 33.

which itself rested on ties. The spikes and rails would soon become loosened and the joints rough and uneven, but with the light cars of the time they could be used, although to the great discomfort of the passengers.

Fig. 34 represents a car-rail of the same type used on curves.

FIG. 34.

The sharp edge of Fig. 33 made it very difficult for teams to cross the tracks, and consequently the type shown in Fig. 35 was adopted. This allows heavily loaded teams to cross the tracks more rapidly, but gives no better service to either cars or passengers.

Fig. 36 shows a further development with a groove for the flange of the wheel, but without the modification of Fig. 35, allowing the passage of wagons over the tracks.

Fig. 37 shows what was generally known as the centre-bearing

rail. This is practically Fig. 36 doubled. It has been claimed by many, if not admitted by the companies themselves, that the main object of this rail was to make the track as obnoxious as possible to vehicular traffic, and any one who has seen this construction in a paved street can see that it has pretty successfully accom-

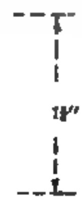


FIG. 35.

FIG. 36.

FIG. 37.

plished its purpose. When it is laid in duplicate, with two rails on one stringer as it existed in Fourteenth Street, New York City, in the spring of 1900, it would seem as if it had fulfilled its purpose beyond the utmost expectations of the street-car companies themselves. It was expected that when one side of the rail was

worn out it could be turned end for end and used on the other side.

About this time an attempt was made to construct a rail with a renewable head, it being recognized that while the head of the rail might be worn out, the lower part and base would be as good as ever. In order to accomplish this the rails were made in two parts, so that when it was worn it could be taken out and renewed without disturbing the ties or the base of the rail even. Fig. 38 shows a type of this rail.

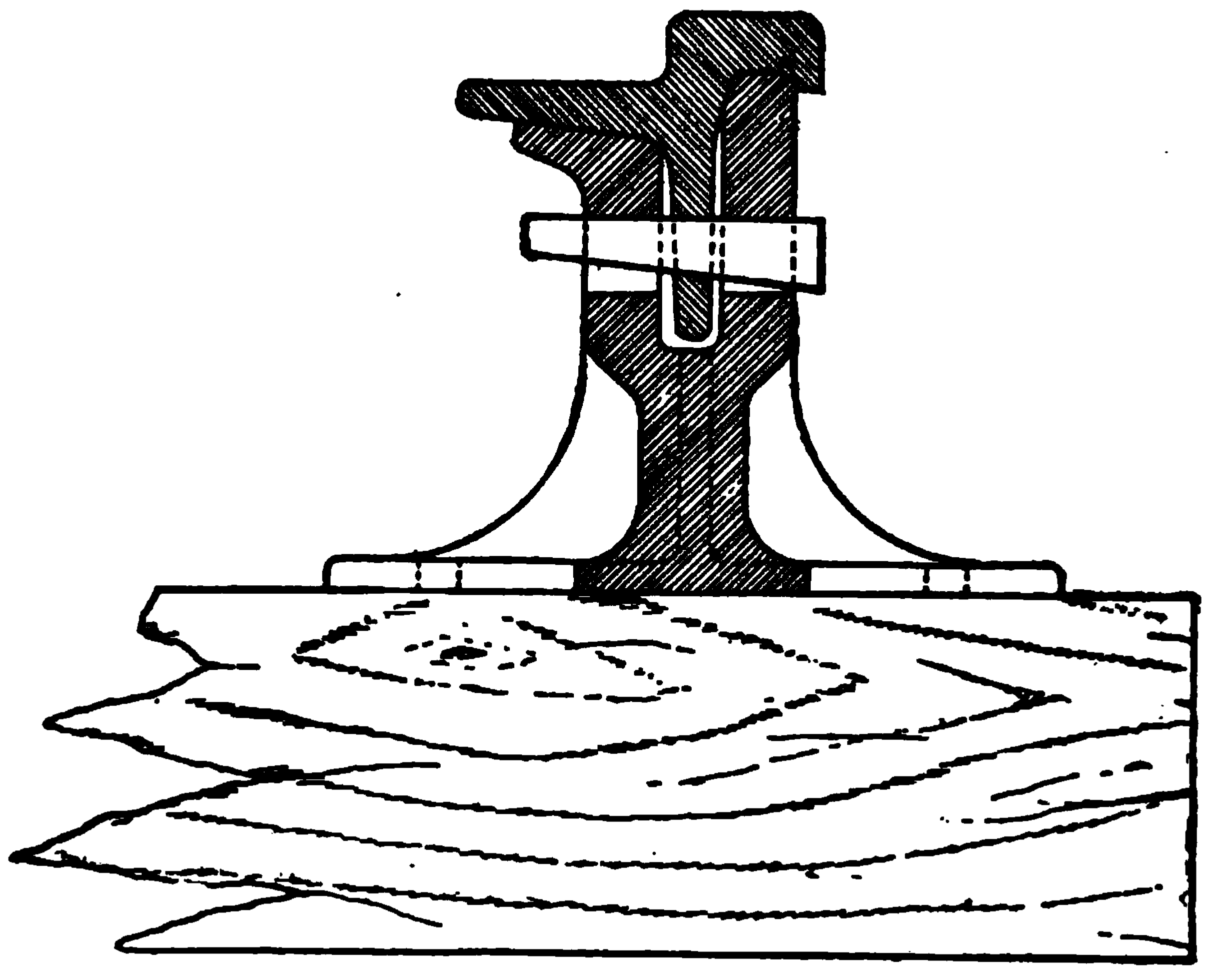


FIG. 38.

Fig. 39 shows a rail built somewhat on this plan, but differing in detail, the rail itself being supported on iron chairs which were spiked to the ties. Quite a large quantity of these rails was used in Brooklyn, N. Y.

When it became necessary in the development of street-railways to change the power from horses to electricity, it was soon discovered that it would be impossible to operate the cars on much of the construction that has been described. Consequently new forms of rail were attempted, and steel was used in their construction. Fig. 40 shows the girder rail that was designed practically on the lines of Fig. 37, with all of its objectionable features.

Fig. 39.

Fig. 40.

Fig. 41 shows what is known as the side-bearing rail. This form, with slight modifications, has been used perhaps more in American cities than any other type. It makes a good roadway for vehicles, but it is difficult for a loaded team to turn out from the track. On account also of its wide tram it is very difficult to pave up to it with any kind of block pavement, as any little settlement at the end of a block will bring the block below the tram of the rail, when abnormal wear will arise and a rut soon form.

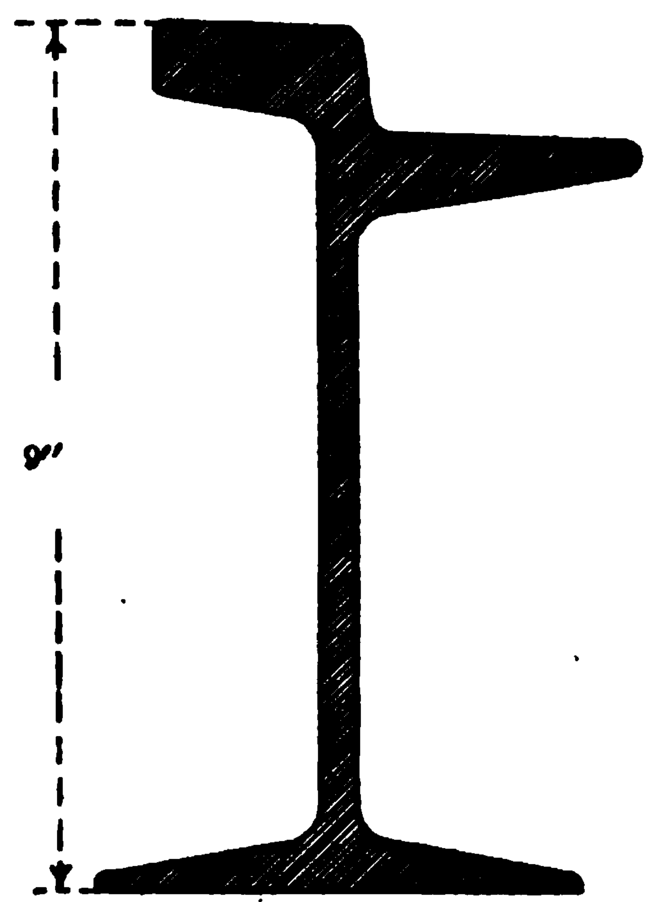


FIG. 41.

Fig. 42 shows a grooved rail that has been used to a great extent in New York City and is known as the Trilby rail. The lip of this rail is extended to a considerable distance beyond the groove, allowing the wheel of any vehicle whose wheel-base is slightly less than the gauge of the track to run on the iron lip rather than inside, as it otherwise would, with the liability of forming a rut. This has the same objection as regards paving as Fig. 41, and the lip of the rail is also kept a short distance below the head. This is objectionable, because it provides a guide to a certain extent for wheels and serves to keep the horses travelling on the track, as they easily learn the line of least resistance and are guided by very slight changes. The typical rail should be one that would neither invite nor repel traffic, and

of such shape that horses could not tell whether the wheels were or were not following the track.

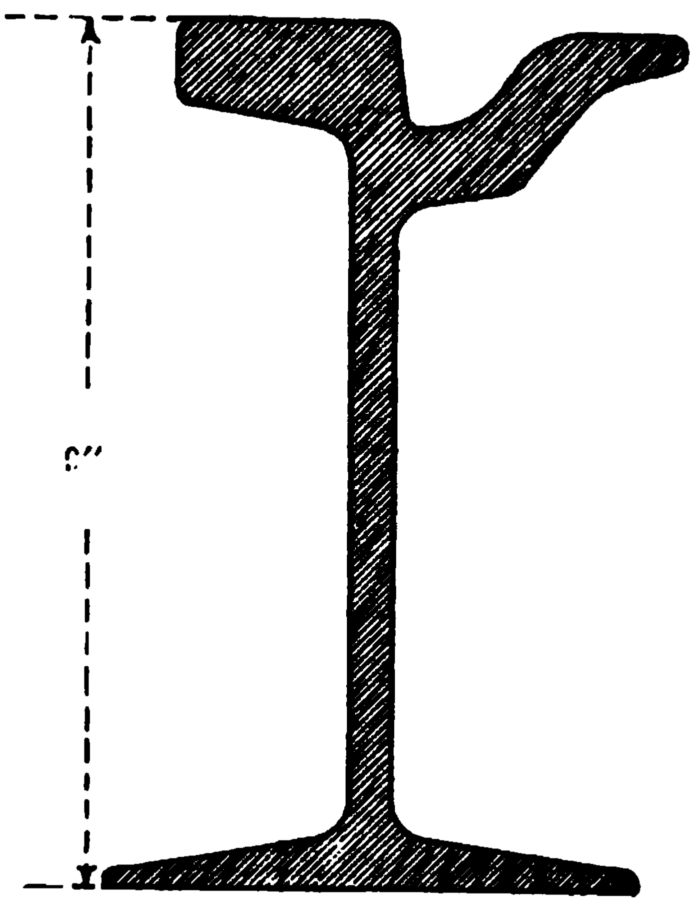


FIG. 42.

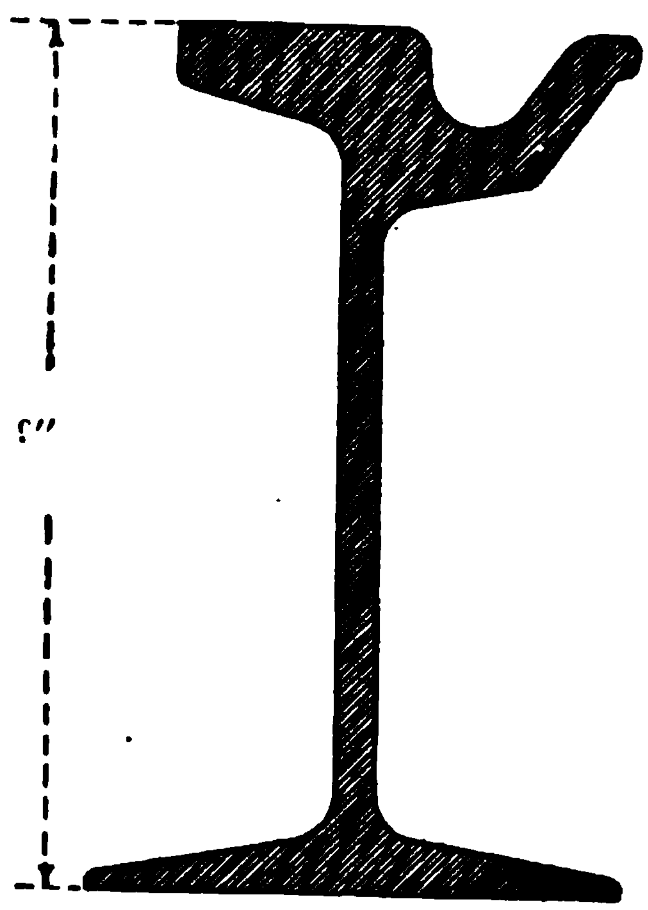


FIG. 43.

Fig. 43 shows a modification of this rail, designed by a former Chief Engineer of the Brooklyn Heights Railway Co., which avoids the objections spoken of.

The street-car companies object to the grooved rail on account of the difficulty with which the groove is kept clean. This is particularly important with electric traction. This last rail was designed especially with the groove formed in such a way that it would be kept clean by the action of the wheel-flange.

Fig. 44 shows a section of a grooved rail used by the West End Street-Car Co. of Boston. This has a lip with a groove quite a distance below the slot of the rail and would be a decided guide to wheels.

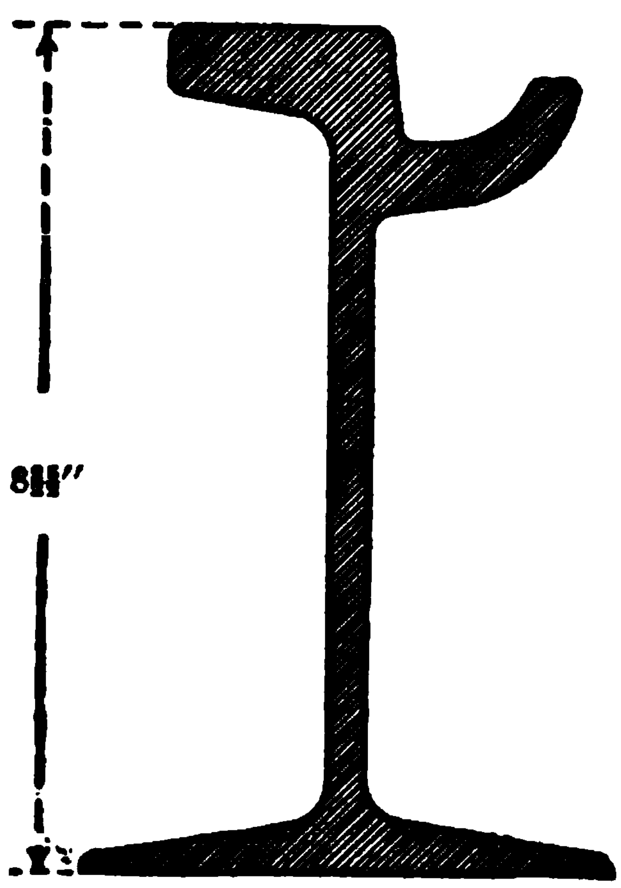


FIG. 44.

Fig. 45 shows a section of a rail used in the Boston subway. This, it will be seen, is a simple tee rail with a flange bolted on, forming a groove. This, being used in the subway is of course not objectionable.

It is generally conceded that the tee rail as used on steam-railroads is the most economical rail for any track, and the modifications here shown are made on account of the pavement and other requirements peculiar to street-railways, but on country roads where traffic is comparatively light, and the rails form no great obstruction on account of location, etc., the rail as shown in Fig. 46 can be used to good advantage to the railway company and no detriment to the public.

The street-car companies recognize the necessity of a permanent

Fig. 45.

Fig. 46.

construction in the improved pavements, and for the last four or five years have been experimenting with a view to obtaining the best and most economical method of construction.

Fig. 47 shows a section of a track as laid on a street paved with asphalt in Buffalo by the Buffalo Railway Co. It will be noticed that both ties and rails rest on concrete, giving a construction that is absolutely rigid, except what resilience is gained from the elasticity of the ties. In speaking of this plan, a representative of the company says that they have used concrete construction in Buffalo since 1897. The rails themselves rest directly on concrete beams and are held to gauge by tie-rods. In this construction the concrete beam was formed and allowed to set, and then the rails were placed upon the beams with steel ties, and, after being sur-

FIG. 47.

faced with wedges, the space between the concrete beam and the rail was filled with grouting.

In 1899, however, the construction was changed to that as shown in the figure. The rails were 9 inches deep and 60 feet long. They were drilled for tie-rods every 10 feet and with one hole only at each end, the rail being temporarily fastened with spliced bars. Oak ties 5 inches by 7 inches by 7 feet were used, spaced 5 feet from centre to centre, every other tie being tamped with crushed stone and the surfacing and lining being done by means of these ties. The alternate ties were then tamped with concrete their entire length, and a beam of concrete about 8 inches deep and 15 inches wide was laid under the rail. The use of the stone-tamped ties was for the purpose of expediting the work, as the track could be spiked, gauged, lined, and surfaced by means of them quicker than if the concrete beam was first made.

In places where common paving was used the amount of concrete included in the above statement was all that was required, but where block paving was laid the space between the ties and for a distance of 2 feet outside of the rail was filled with a 6-inch layer of concrete as a foundation for the paving. All concrete was laid of the best grade of Portland cement in the proportion of one part of cement, three of sand, and five of broken stone.

During the process of spiking, lining, etc., the rails were joined temporarily with space-bars, two bolts only being used to a joint. After the concrete had set for 72 hours the bolts were removed and the joints electrically welded. For this purpose an ordinary Bessemer bar, 3 inches wide, 1 inch thick, and 15 inches long was used, one on each side of the web of the rail, and three welds were made on a joint, one at each end of the bar and one at the point where the rails abutted. The company did not deem it necessary to introduce expansion-joints to take care of expansion and contraction, and in the spring of 1900 still thought that they were right.

The company states that under the old method they could lay about 500 feet of track per day, but with that just described they were able to lay 2500 feet in the same time. The officials say all their track on concrete beam is in first-class shape, making very smooth riding, with little or no inequalities in the surface.

Fig. 48 shows the construction in a common stone pavement.

FIG. 48.

It differs from the above in having the concrete only under the ties and in the beam under the rails. It will be noticed in Fig. 47 as well as Fig. 48 that, although the street itself is paved with asphalt, the space between the rails and tracks is paved with stone. It is without doubt more economical for the railway company.

Fig. 49 shows the standard tie construction of the Borough of

Brooklyn, New York City, as established by the Department of Highways for streets paved with stone on a concrete base. This requires 6 inches of concrete under the ties, and would make a thickness between the ties of 12 inches.

Fig. 50 shows the construction recommended with a concrete beam under the same conditions as above. A portion of track was constructed in this manner in 1899. No standard has been adopted at the present time for an asphalt pavement.

In Toronto, Can., by the terms of an agreement between the city and the Toronto Railway Co., a permanent track-construction was required whenever the streets should be paved with a permanent pavement.

Fig. 51 shows a section of a track as per their standard adopted in 1892. The rail weighed 73 pounds per yard, but it is said at the present time that with their experience they would now lay a heavier rail. This was one of the first, if not the first, of the attempts made to lay street-car rails on a firm concrete base, and has proved entirely satisfactory. In the early asphalt pavements the space between the rails and tracks was paved with asphalt, but from the experience there it has been deemed best in the future to pave that space with blocks. At first granite was used, but so much complaint was made by bicyclists that Scoria blocks imported from England were used instead. In 1892 there were laid 29.9 miles of single track, at an expense of $322,555; in 1893, 26.1 miles of single track, at an expense of $392,030; in 1894, 9.8 miles of single track, at an expense of $116,942.61.

In Sioux City, Ia., in 1897 street pavements of brick and asphalt were ordered for streets in which were located the tracks of the Sioux City Traction Co. After studying the situation, the company adopted the plan shown in Fig. 52 for asphalt pavements. The construction for brick pavements was the same except that the groove was made by a specially shaped brick. The company had used tee rails in some instances without any objection being made, and for that reason 6-inch tee rails, 60 feet long, were adopted to be laid on steel ties spaced 3 feet from centre to centre. The rails were joined by 26-inch bolt-spliced bars and separated by $\frac{3}{8} \times 1\frac{1}{2}$-inch steel tie-rods, spaced 7 feet 6 inches between centres.

Under each rail were laid continuous beams of Portland-

FIG. 49.

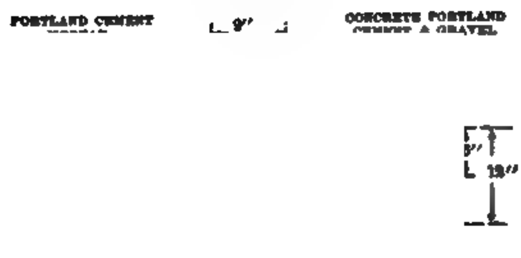


FIG. 50.

FIG. 51.

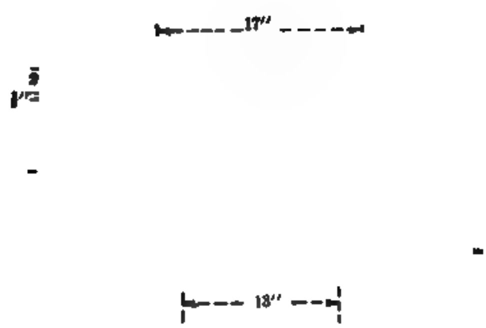


FIG. 52.

cement concrete of an average width of 15 inches and a depth of 9 inches. At the joints the rails rested upon a steel plate $\frac{3}{8}'' \times 6'' \times 24''$, bedded on a concrete beam. The concrete of the beam was formed of one part of Portland cement, two and one-half parts of sand, and five parts of broken stone. On curves and in special work, instead of the concrete beam, oak ties were used bedded in 6 inches of concrete similar to that above described. After the subgrade had been prepared the rails were placed in position, the track made up, surfaced, lined, and gauged, resting on wooden blocks placed under each rail every 8 or 10 feet. The contractor then excavated under the rails and placed in position the wooden forms of the beams.

The concrete for the foundation of the pavement was then laid between the rails, being thoroughly tamped up under the ties so as to fill the corrugations. After this concrete had received one day's set, the wooden forms were removed and the concrete beam placed in the trench which was left for it, and thoroughly tamped up under the rail so as to cover the rail-flange. The concrete in the beams was allowed to set for eight days before the track was used.

During these eight days the track was naturally exposed to changes of temperature, and as it was laid during extremely hot weather, the temperature changes were extreme between day and night. The amount of expansion and contraction was found to be from 3 to 4½ inches in 400 feet. In order to protect the track from these changes in temperature, the rails were covered with V-shaped troughs made from boards 12 inches wide and 7 feet 6 inches long, so that the trough could be set between the tie-rods.

In a brick pavement where sand was to be used on the foundation, the rails were covered with sand previous to placing the troughs over them. In the asphalt pavement the troughs were used until the beam was put in, when the toothing-blocks were laid as fast as the beam was constructed, affording the same protection from temperature as did the sand on the brick streets. This device successfully prevented any trouble from expansion.

On the brick streets on the outside of the rails the brick was laid up close to the head of the rail, the space between the two flanges of the rail being filled with cement mortar, but on the

inside special brick were provided, made of such shape that they would extend under the head and butt up tightly against the flange. On the asphalt streets toothing-blocks were laid alternately as headers and stretchers, the space between the flange being filled as before. On the inside, however, the blocks were brought to within 1¼ inches of the head of the rail, and the space between the block and flange to within 1¼ inches of the top, being filled with cement mortar, and the space above this cement mortar being filled with specially prepared asphaltic cement, the street-car company running a car over the track to form a groove with the flange of a wheel. It is said that, although this track was laid in the hottest weather, none of the joints opened in the winter, and a careful examination could discover only about 30 per cent of the joints.

The above description was taken from the *Street Railway Journal* for August, 1898.

In March, 1900, the general manager of this road says: "We have not expended one penny in maintaining it since it was put in, and I consider it as nearly a permanent roadbed-construction as I have ever seen."

Fig. 53 shows the construction adopted by the Third Avenue

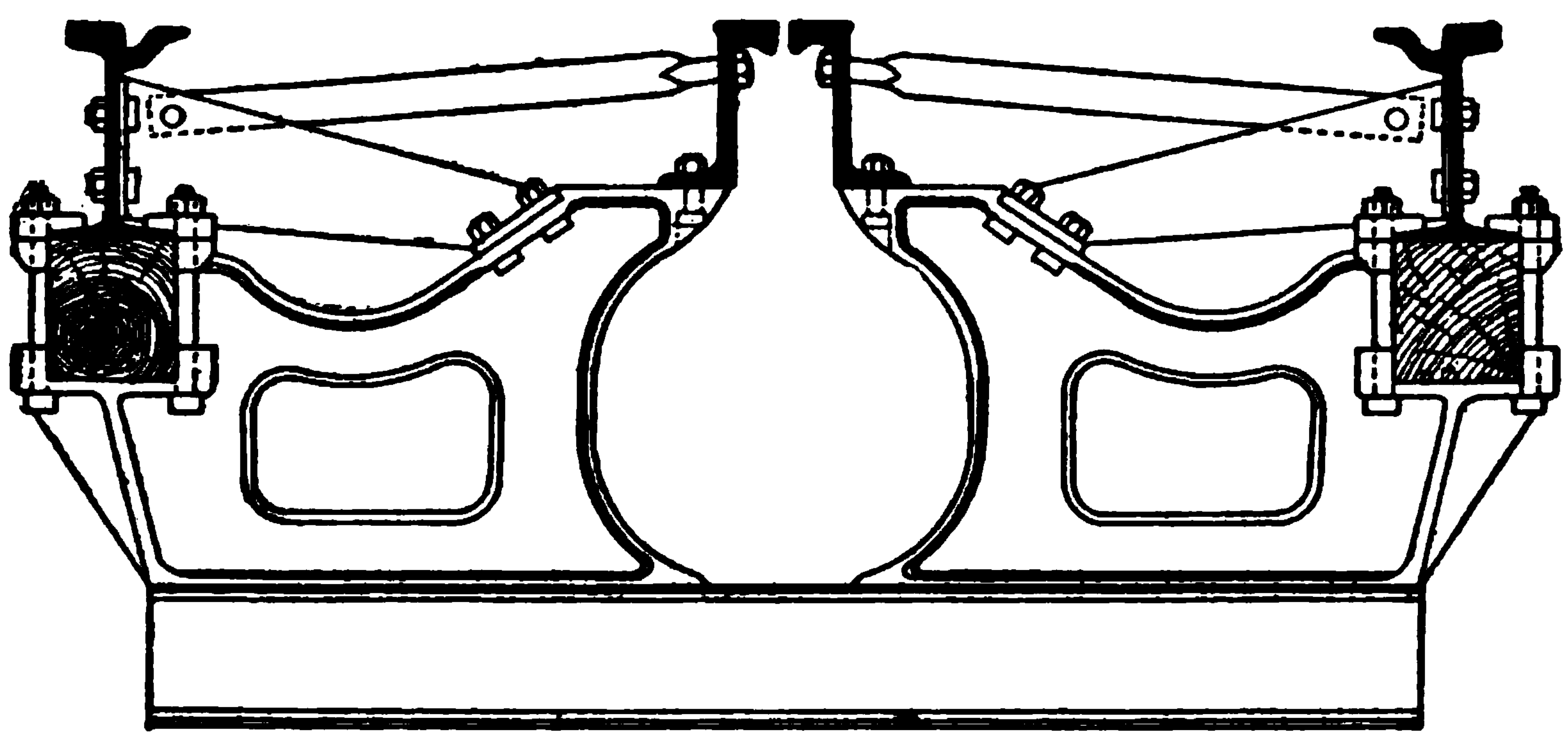


FIG 53.

Railway Co. of New York City when it substituted electric traction for cables. It is not intended to show the entire detail of the work, but only that which would affect the pavement. It will be noticed that the rail is the regularly adopted Trilby rail set on

a wooden creosoted beam. The object of this beam is to give a certain amount of elasticity to the track, so as to make it smoother and more comfortable to passengers. The yokes were spaced 5 feet apart from centre to centre.

The above construction was used on the subsidiary lines, but on Third Avenue proper the form of the yoke was somewhat changed, and instead of the creosoted beam a heavy spring was used resting upon the yoke, and upon which the rail rested. This spring is so designed that when the centre is depressed the ends rise, presenting a corrugated surface of such strength that it is estimated that it will sustain a weight of from 10,000 to 12,000 pounds. The springs are 4 inches wide, and the deflection at the passage of a loaded car carrying about 6400 pounds on each wheel is about $\frac{1}{32}$ of an inch and is noticeable from the street.

From a pavement standpoint it would seem that a wood construction would be better than the spring, especially if laid in an asphalt pavement, as a real deflection of $\frac{1}{32}$ of an inch would break the joint between the asphalt and the rail enough to permit the entrance of moisture, which would naturally lead to disintegration. In Third Avenue, however, the pavement outside of the track is granite block, but, the space between the conduit-slot and the rail being so narrow, it was deemed best to pave this with asphalt. Concrete was laid to within 2 inches of the top of the rail, when about 1 inch of asphalt pavement was spread over the surface in which was bedded a specially designed grillwork of $\frac{3}{4}$-inch cast-iron bars, forming squares about $3\frac{1}{2}$ inches in size. More asphalt was then filled in on top of that first laid, in and around the iron, and thoroughly rolled and compacted so that its finished surface was in a straight line between the slot and the head of the rail.

Fig. 54 represents the permanent construction of railway-tracks in an asphalt street in Detroit, Mich. This shows the space between the tracks and rails paved with brick or stone blocks. The special part of this construction is the tie-bar which is bolted to the base of the rail, there being no connection at all between the webs as in the other methods heretofore shown. The Detroit Railway Co. consider that this method of construction is a success. While the tie connecting the webs of the rail is not

particularly objectionable in an asphalt pavement, as the concrete is filled all around it, it is decidedly so in a stone block pavement. It often happens that the ties are not exactly square with the

FIG. 54.

track, and, in any event, it makes it necessary to use a certain number of courses of blocks between the ties, which often makes the joints wider than is desired.

Fig. 55 shows the tie-construction in an asphalt pavement in Cincinnati, O. This city was one of the first cities to adopt con-

FIG. 55.

crete construction, and, as is shown in the cut, lays concrete under all the ties and, in the case of asphalt, over them as well, so that the tie is entirely surrounded with concrete. Very satisfactory results have been obtained from this kind of construction.

In the city of Rochester, N. Y., when a street is permanently paved the city orders the street-car company to construct a per-

manent pavement between its tracks and for a space of 2 feet outside. If the company shows no disposition to do this, the city authorities advertise the work and have it done under a separate contract from the pavement proper, and the expense of the same is charged to the street-railway company. While this method might bring about some conflict on account of having two contractors on the same street, as a matter of fact the work of the street-railway company has always been performed by the same contractor as the street pavement.

Fig. 56 shows the construction used in Rochester in 1898. This plan is peculiar in that the ties are all made of old rails.

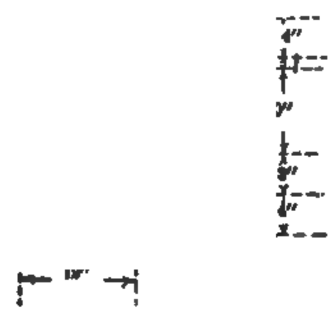


FIG. 56.

The work was all double track, and every third tie was carried across to both tracks; and as the rails were rigidly bolted to the ties, the entire work was really one piece of construction. As in the Sioux City work previously described, the track was gauged, lined up, and blocked up to grade before any concrete work was performed. The concrete between and under the ties, as well as in the concrete beam under the rail, was then laid and thoroughly tamped under and about the old and new rails. The concrete in the track-construction is composed of one part of Portland cement, three of sand, and six of stone. This particular construction relates to brick pavement. Where wooden ties are used instead of the iron ones just described, the concrete extends under and between the ties as in the Cincinnati construction.

Fig. 57 shows the Rochester construction for asphalt with the concrete beams. The space between the rails is paved with stone

blocks, the asphalt being laid up to the outside of the rail. In this instance the rails were clamped to a concrete beam as shown in Fig. 58, there being three clamps to a 30-foot rail, and five to one 60 feet in length. A cushion of asphalt mastic ½ inch thick is laid on top of the concrete beam to make the bearing of the rail more elastic. Attention is called to the provision made for drain-

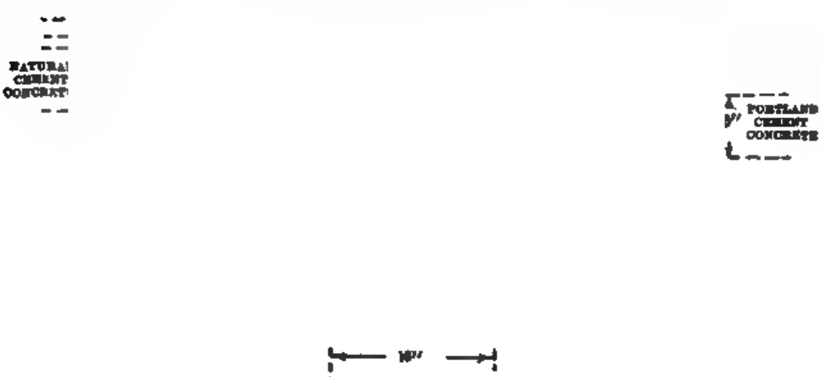


FIG. 57.

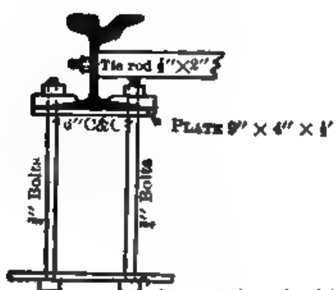


FIG. 58.

age, should any water seep through the joints of the blocks down to the sand cushion. It will be noticed that drain-tiles are laid about 1 foot inside of the outside rails, in about the same location as in the Toronto plan.

In 1897 it was necessary in an extension to some street-railway lines in Yonkers, N. Y., to construct a track in an asphalt pavement already laid. In this particular instance the concrete

beam was undoubtedly the cheapest, as it admitted of a track being constructed with the least disturbance of the pavement. Two channels to receive the rails were cut in the asphalt, 12 inches wide at the surface and 18 inches at the bottom, a total depth of 18 inches. Channels were also cut transversely down to the top of the concrete beam for placing the tie-bars, which consisted of angle-irons to which the rails were bolted. The method in detail is shown in Fig. 59. In cutting through the asphalt it

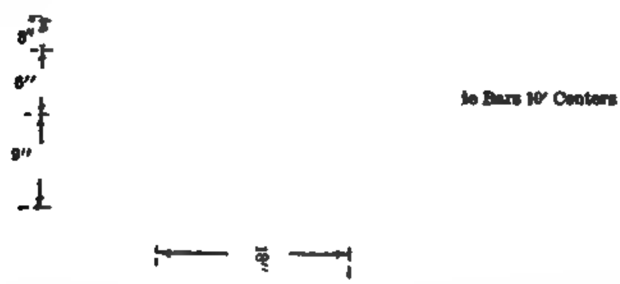


Fig. 59.

was found cheaper to burn through the wearing surface with a No. 8 iron wire, heated by connecting it with the trolley wire already erected overhead, and stretching the iron wire along the lines marked for the edges of the opening.

Fig. 60.

Fig. 60 shows the construction adopted in Minneapolis by the Twin City Rapid Transit Co. The method of construction was described by Mr. Cappelen in a discussion on the "Influence of

Rails on Pavement" before the American Society of Civil Engineers:

"The ties were first laid on a prepared subgrade 6 to 8 feet apart, and the rails lined up and temporarily fastened to the ties. Cast-iron joints were made and a concrete beam put in between the ties. The ties were then pulled out and the space filled and the balance of the street concreted. The rails were also spiked to the concrete beam as soon as it was in place. The track was kept in perfect alignment in this way. After discussing the work as it progressed a further modification in constructing the beam was adopted. As it was not always possible to follow with the concrete work of the street proper as fast as the beam was built, a good bond was not obtained between the beam and the other concrete; so the method was changed. The ordinary concrete was put down outside and inside of the rails, forming a rough groove about 8 inches deep, 15 inches wide at the bottom, and 18 to 20 inches at the top. In this groove as soon as it was built the beam of concrete was placed. Otherwise the construction was as before."

The cost of this work as stated by Mr. Cappelen was about $33,908 per mile of double track, including the asphalt pavement.

When the street-car service of Dublin, Ireland, was remodelled several years ago, the principle of having the track-construction a part of the pavement was recognized, and concrete was laid on the street as if the pavement only were to be laid. The rails were of the side-bearing pattern, 7 inches deep and 7 inches wide at the base, and were laid directly on the concrete base and the blocks paved in about them.

The foregoing illustrations of street-car track-construction show very conclusively that the street-railway companies realize and understand that the best method is the most economical, and that the different companies are earnestly searching for what is the best method.

In determining the exact construction of a street-railway track for any street, there must be taken into consideration the kind of pavement to be laid, the amount of traffic on the street, the traffic of the railway, and the power used to propel the cars.

The kind of pavement on the street will govern to a certain

extent the form of rail to be used, and many details of construction if the pavement be of asphalt. The traffic of the street will be the governing principle as to the character of the pavement next the rail. It is a well-recognized fact by street-railway officials that when cars are operated by external power, such as cable or animals, the wear and tear on the track is much less than when electricity or compressed air is used, on account of the friction on the rails. When the wheels are turned by motors attached to their axles, the grinding effect of the wheels on the rails wears them out very materially, and much faster than on a cable road. This is illustrated very plainly by the increased wear that is always noticeable on an up-grade track over the track used by down-grade cars, especially where the cars are moved by the friction on the rails.

It is extremely difficult to estimate in advance the life of the rail of a street-railway. It is generally measured by the number of cars passing over it. Some engineers give as the average life of the ordinary steel rail the passage of 6,000,000 cars over it. On a track laid in Brooklyn, on Fulton Street between Brooklyn Bridge and the City Hall, in 1895, the rails were renewed in 1899. The traffic on this piece of track has been estimated for that period as being one car for every fifty seconds during twenty-four hours. This would mean the passage of 2,522,880 cars over the track before it was renewed. It is stated that after 2,500,000 cars had passed over the tracks of the Third Avenue Railroad in New York City the rails were appreciably worn and hollowed out in some instances, although the road was operated by cable and the track was solidly and substantially built.

Mr. Owen, in a paper before the American Society of Civil Engineers, gives as the approximate life of a rail ten years, and Mr. Bowen, in a paper presented to the American Street Railway Association in October, 1896, estimated that the rails of a cable-track in State Street, Chicago, would last twelve years.

In all of these cases the rails would require renewing before any improved pavement would be relaid, provided that both constructions were carried out at the same time, so that a construction should be adopted that would provide for the renewal of the rails at the least possible expenditure of labor.

One of the great sources of trouble to any car-track, whether operated by steam or electricity, is at the joints of the rails. A great many devices have been employed for the purpose of making these joints as nearly perfect and as much like the remainder of the rail as possible. How important this is can be understood by another statement by Mr. Bowen in the paper previously referred to, in which he says that when the question came before him of renewing the State Street track in Chicago, he had a car weighing over four tons run over it, attached to a grip-car by means of a dynamometer. The same car was run over a track newly laid and at the same speed as over the old line. The dynamometer showed that it took 13.75 pounds more pull per ton to haul the car over the old line than over the new. That he attributed a great deal of this extra power required to the condition of the track at the joints can be seen from his conclusion that a new track with cast joints would last twelve years, and as there will be no low joints, the draw-bar pull will not increase much until the rail is worn down sufficiently to allow the wheel to run on the flange.

When it is remembered that some engineers figure that the force required to haul a ton on a well-constructed track should not exceed 8 pounds, the effect of the track being in bad condition can be plainly understood.

This trouble to joints has been obviated to a great extent by the recent practice of increasing the length of the rails from 30 to 60 feet. This reduces the number of joints one-half at once, and the average cost per rail is increased only about $2 per ton by extra length. Since electricity has been so generally introduced upon street railways as a motive power, and the rails have been used as a return conductor for the electricity, a great deal of attention has been paid to the joints. What is known as the cast-iron joint has been used with good success. This joint has been described in Mr. Bowen's paper as follows:

"The rails at the joint are scraped and brightened. A cast-iron mould is placed around the joint, making a tight fit. Into this molten iron 25 per cent scrap, 25 per cent soft and 50 per cent hard silicious pig iron is poured. The metal in contact with the mould begins to cool and form a crust, while the interior remains molten. This crust continues to cool and at the same time

contracts, forcing the molten metal strongly towards the centre, which makes a solid and rigid joint. The top and bottom part of the ball of the rail is afterwards filed off perfectly level, so that it is very difficult to detect the joint by riding over it or looking for it. Upon breaking the joint which has been cast welded, three spots will usually be found where amalgamation has taken place between the rail and the cast portion, one on each side of the web of the rail, and the other on the bottom."

He says that 17,000 joints were made in Chicago during the year 1895, and of these only 154 were lost, and that the joint in comparative tests has been shown to be far stronger than the rail itself, and that breakages that have occurred were due to flaws in the metal. The metal cast around the joint has eight times the cross-section area of the rail. Therefore, if the cast iron has one-fourth the strength of steel, the joint will be twice as strong as the rail.

In Brooklyn, N. Y., 1600 of these cast joints were made in 1896, and only one failed during the first six months. In 2000 joints made by another company forty had broken.

Another method of welding rails has been described under "The Method of Track Construction in Buffalo." It was considered doubtful by many engineers whether such construction would be successful on account of its expansion and contraction due to changes in temperature, but it would seem from the few failures that not as great changes in temperature occurred as was expected. This is due doubtless to the rail being almost entirely surrounded by the pavement, preventing any direct action of the sun and keeping the greater part of the rail at the temperature of the pavement, so that no buckling has occurred on account of the heat, and that the elasticity of the rail or joint has been sufficient to take up the contraction due to cold weather. At all events, there seems to have been no trouble on that account from changes of temperature.

Coming now to the discussion of what is the best construction for a railway track in different improved pavements, Fig. 61 will show the method which the author would recommend for a street to be paved with granite. The rail is that shown in either Fig. 42 or Fig. 43 as may be deemed best by local authorities. The ties

should be of steel, spaced 10 feet apart and of the kind shown in either the Sioux City or Yonkers construction, and resting on top of a concrete beam, there being no connection whatever between the web of the rails. The objection urged to this method, that the rails cannot be kept in gauge, does not seem

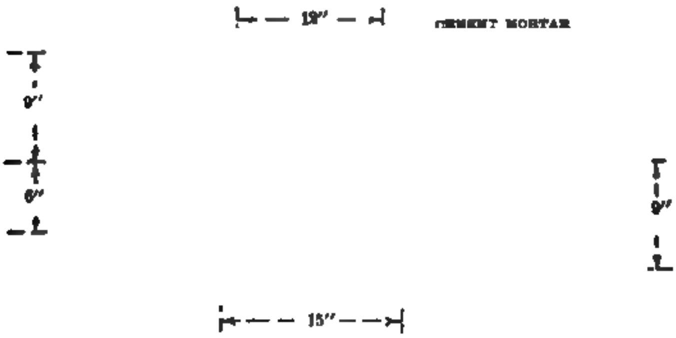


FIG. 61.

valid when it has been used successfully by many companies, and when with the ordinary wooden-tie construction the tie is simply held to gauge by spikes on the bottom flange. With the method proposed, and a solid granite pavement built tight against the rail, it would seem that no difficulty would be encountered in keeping the rails to line and gauge.

Fig. 62 shows the plan proposed for the construction on a street

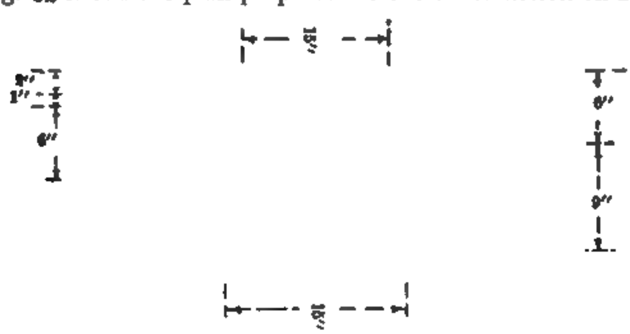


FIG. 62.

paved with asphalt. The rail is the same shape as that recommended for granite, except that it is but 6 inches deep. The rail

can be made of any required area to give the necessary strength, and the metal can be used to better advantage on a shallow rail, and with asphalt as great depth is not required as when granite block is laid. The arrangement of ties would be the same as in the other case, except that if the street-railway authorities have any preference for a tie from web to web of the rails, there would be no objection, as the concrete base for the asphalt can be laid around the ties without any difficulty.

There is considerable difference in the practice of different engineers as to whether asphalt should be laid up to the rails or whether blocks of some kind should be used. This will depend to a great extent upon the conditions of the street traffic. If the traffic be light, and the above construction is used, there can be no objection to finishing with asphalt up to the rails. Great care, however, must be exercised in doing this, and the asphalt should be tamped solidly under the lip and head of the rail, so that if wheels run along next to the rail, the asphalt will be sufficiently strong to resist the tendency to rut. In some cities, however, the entire space between the tracks and rails is paved with stone blocks, as many engineers think that this is a better construction. That it is more economical is probably true; but if the street be comparatively narrow, only a small portion of the street will be paved with asphalt if all of the track-space is paved with stone. In some streets also it is considered necessary to lay blocks of stone or brick on the outside of the rail as well as inside, and where the street-traffic is heavy this may be advisable. It should be remembered, however, that the theory of this construction of stone or brick is to prevent the tendency of the wheels to rut the pavement alongside the rails; but if, in the construction of a track, a rail is used that will present practically the same surface to traffic as the remainder of the street, neither inviting nor repelling wheels, this tendency is materially reduced.

The recommendation, however, would be, on streets of moderately heavy traffic, to place a row of toothing-stones arranged in pairs and set as headers on the inside of the rail, and on the outside lay the asphalt next to the rail. If the distance between the curbs is so wide that there is plenty of room outside of the track for the street-travel, and the street-railway authorities, for economi-

cal reasons, wish to lay stone or brick pavement between the rails, there would be no particular objection if it be done in a thorough and substantial manner.

Fig. 63 represents a recommendation for a brick pavement. This is substantially the same as that shown in Fig. 62, except that no tie-rods should be used between the rails but at the base upon the concrete beam as recommended for granite. It is very difficult in using tie-rods between the webs to so place the holes that the rods will be exactly perpendicular to the rails, and

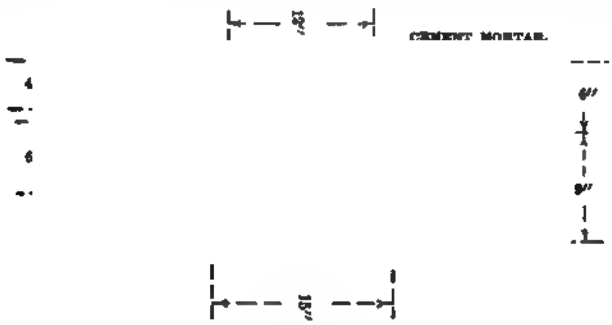


FIG. 63.

trouble always occurs in laying the blocks, whether of stone or brick, between these bars on that account. It also makes an extra-wide joint wherever these rods occur, and satisfactory results can never be obtained in that way.

The space between the upper and the lower flange of the rail, on the outside and on the inside, must be filled when a block pavement of any kind is to be used. Untreated and creosoted wood, sand, cement mortar, and specially burned tiling have been used for this purpose. Wood is probably the cheapest, and if the track is to sustain heavy traffic, so that it will require renewal every five or six years, untreated wood will probably be satisfactory; but if it is to remain ten or twelve years, it should be creosoted, so as to prevent decay before the rails will require renewing. Cement mortar gives good results, but is considered expensive and can be used but once. Specially burned bricks have been used with good results, although some engineers object to them on account of their being easily crushed.

Whatever material is used for this filling, the space between it and the blocks and rails should be completely filled with the same filler as that used in the block pavement, whether paving-cement or cement grout, so as to prevent the admission of water around the rail. Whatever the block construction is next to the rail, whether stone or brick, or whether used in the entire pavement or only as a protection to the asphalt next to the rail, the blocks should be bedded firmly in good cement mortar resting on a concrete base, so that they will remain firmly in place without any settlement under travel and be as rigid as the rail itself.

If it be desired to use the wooden-tie construction instead of any of the methods shown above, the ties should be laid on a concrete base and the space between and around them filled with concrete to the required height for the base of the pavement. In such a case, where, in asphalt and in brick pavements, the ties would be almost if not entirely surrounded with concrete, it would doubtless be more economical to use a creosoted tie rather than an untreated one, so as to prevent the tearing up of the concrete to renew the ties, as the untreated tie would require renewal much oftener than the treated one. The extra expense involved, assuming the cost of creosoting to be 25 cents per tie, would be about $700 per mile of single track, but under the conditions mentioned above this expense would be justifiable.

If it be necessary to lay a street-car track in the middle of a macadam road or a macadamized street, the best results would be obtained by the method recommended for stone pavements, the space between the tracks and rails being paved substantially with stone.

In the suburbs of Boston are a great many macadamized streets upon which street-railways are operated. In all of these the track-space is paved with stone, as well as from 12 to 18 inches outside. On a road, however, upon which there is not much travel good results have been obtained by laying the tee rails with the ordinary tie-construction. The flange of the wheel maintains for itself a groove along the rail. While this will probably require some attention, especially for maintenance between the rails, it will in the end give very satisfactory results.

It seems almost impossible, however, to keep light teams out-

side the tracks even on a macadam street; so where the street-traffic is considerable, the best method is, as has been stated, to pave the track-space with stone.

It often happens that it becomes necessary to lay improved pavement on a street where a street-car track already exists and in good condition, with rails similar to that shown in Fig. 41. In such cases the pavement, whatever its nature, should be laid between rails on the same level as the head of the rail. Otherwise the surface will be bad for vehicles crossing the track. In order to accomplish this without relaying the track with a grooved rail, it will be necessary to lay some foreign material next to the rail to form a groove.

A device to accomplish this, shown in Fig. 64, has been patented

Fig. 64.

by Mr. Buckland in Springfield, Mass. It consists, as is shown in the figure, of cast-iron blocks made to fit over the tram of the rail, and in such shape as to form the required groove. This costs about $2500 per mile of track, and is said to have given good satisfaction where it has been used.

When brick is used for the paving material, specially moulded blocks have been used both on the outside and inside of the rails. When asphalt is used for the paving material, granite toothing-blocks can be successfully employed by setting them as headers

against the rail, as heretofore recommended, and bedding them solidly with cement mortar.

In Glasgow, Scotland, where paving material of any kind is laid against the track on each side of the rail, alternating with the blocks is laid a chilled-steel block casting, 4½ inches square, and roughened on top so as to give a foothold to horses. The block is cast hollow in order to save material, and the alternating stone block is of the regular size as that used on the rest of the street. This with the rail gives a solid and unyielding bearing to wheel-traffic, and absolutely prevents any ruts forming next to the rail.

The examples of street-car track construction previously given in this chapter show the method of track construction up

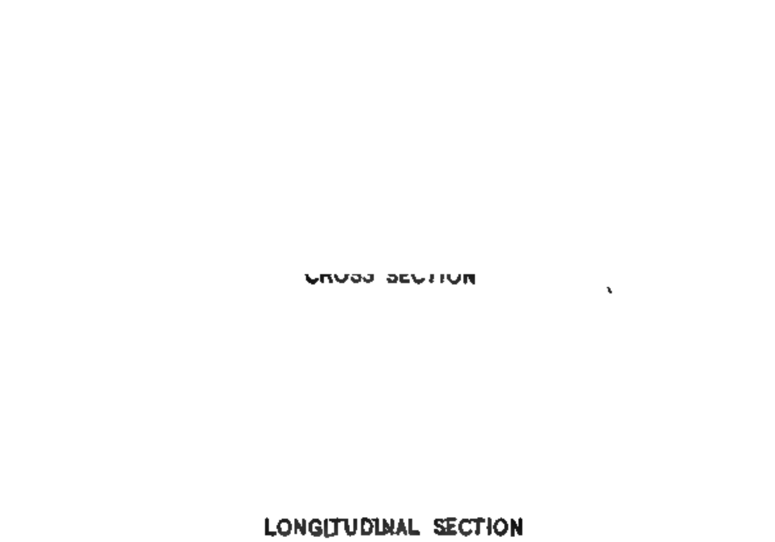


Fig. 66.

to 1900. Those which follow are examples of what is considered the best practice in the principal cities of the country to-day. It will be noticed that none of the examples given show the construction with concrete beams, which was used to a certain extent ten years ago, and that all of the companies lay their ties in or upon cement concrete or broken stone ballast, it having

undoubtedly proved economical to make the track construction first class in every respect.

The Coney Island & Brooklyn R.R. Co., in the Borough of

FIG. 66.

Brooklyn, New York City, has recently adopted as its standard construction a base of broken stone 6 inches thick, thoroughly

STANDARD MATERIALS.

Blocks—Granite, 8" to 12" long; 3½ to 4½" wide; 4¾" to 5½" deep; 30 per sq. yd.
Sand—Cow Bay.
Concrete—1 part Portland cement, 3 parts sand, 5 parts 1¼" crushed stone or slag.
Ballast—1½" broken stone or slag.
Rail plaster—1 part cement, 8 parts earth or clay.
Joints—Electric weld.
Ties—As shown, spaced 2'-0" centers, L.L.Y.P. 10 lb. creosoted.
Spikes—$\frac{9}{16}$"x5" standard, 4 to each tie.
Braces—As shown, L. S. Co. pattern, 2 to every second tie.

FIG. 67.

rolled, upon which are laid creosoted ties, the space between the ties being filled with concrete upon which the granite blocks

LONGITUDINAL SECTION

STANDARD STEEL TIE

FIG. 98.

Fig. 69.

are laid, making the completed pavement. The joints between the blocks are filled with cement grout.

Fig. 65 shows the standard construction in Detroit. It will be noticed that although the pavement between the rails is brick, stone block cut so as to form a groove is laid next to the rail, which is the ordinary T rail pattern.

Fig. 66 shows the standard track construction in Kansas City, wood blocks being used for pavement. The style of the rail should be noted, as it varies so materially from those of all the others. The wood blocks are chamfered off on the inside to meet

FIG. 70.

the lower flange of the rail, while the blocks on the outside are laid squarely against the flange.

Fig. 67 shows the standard construction of the Public Service Railway Co. in Newark, N. J. The spaces between the rails and tracks are paved with granite and the rail is the ordinary grooved pattern.

Fig. 68 shows the form of construction used by the Brooklyn Rapid Transit Co. in the Borough of Brooklyn, New York City, in paved streets. This construction was used on one street which was paved outside of the rails with asphalt block and between the tracks and rails with improved granite with cement joints, and the surface of the pavement from curb to curb is practically continuous, the street -car track forming no obstruction to travel.

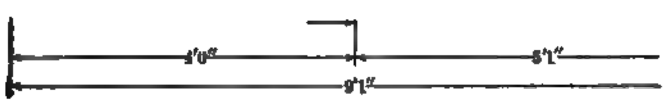
Fig. 69 shows the construction used by the Cleveland Railway Co. This construction does not vary materially from that of the

Brooklyn Rapid Transit Co. in the previous figure, the rails being about the same and both companies using steel ties.

Fig. 70 shows the construction in Philadelphia. This varies materially from the other constructions, the rails being laid on chairs embedded in the concrete.

Fig. 71.

Fig. 71 shows the construction used in Boston, grooved rails being set upon steel ties, as in the case of Cleveland and Brooklyn.



Type No. 2A.

Fig. 72.—Wood Ties in Concrete.

Figs. 72 to 74 show standard types as adopted by the Board of Supervising Engineers of Chicago previous referred to. These

do not differ materially from other modern types shown herewith.

All of the foregoing examples would undoubtedly give a track against which it would be possible to lay any form of pavement so that it could be properly maintained without undue expense to the railroad company.

Many people claim that where a street is paved with asphalt the space between the tracks and rails should be paved with the

TYPE NO. 3.
FIG. 73.—Wood Ties in Crushed Stone.

same. But experience has seemed to demonstrate that if a modern granite pavement is used the public will be well provided for and the pavement can be maintained by the railroad company at much less cost. An instance of this is a portion of Flatbush Avenue, Brooklyn, where the track was laid as shown in Fig. 68, the space inside the rails was paved with improved granite blocks with cement joints, and the outside space with asphalt blocks. The result is a street surface almost unbroken by the tracks and perfectly satisfactory.

Figs. 75 to 81 show types of track construction in different

Fig. 74.

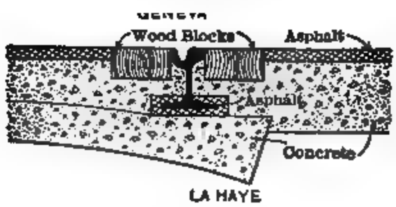


FIG. 75.—Street-railway Track Construction at Geneva and La Haye.

FIG. 76.—Girder Rail in Concrete Base with Asphalt Paving, Bordeaux (France)

6¼′

B

4′8½″ Gage

C

D

Concrete 1.6″

FIG. 77.—Examples of German Street-railway Track Construction.

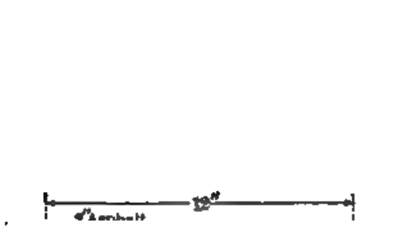
(a) Non-rigid construction at Düsseldorf and Berlin; (b) Semi-rigid construction at Neuchatel; (c) Rigid construction at Neuchatel; (d) Construction with reinforced-concrete blocks at Elberfeld and Brunswick.

cities of Europe as taken from *Engineering News* of May 23, 1912. It will be seen that there is more variation in the work

Fig. 78.—Half Cross-section of Street-railway Track with Hollow Concrete Stringers; Geneva, Switzerland.

Fig. 79.—Track Construction with Reinforced-concrete Longitudinals and Special Shallow Rails, Berlin.

than in this country. Note that at La Haye the rail, while set in concrete, is bedded in asphalt to render the track more elastic,



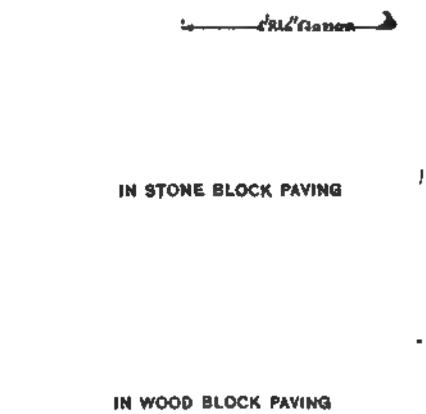


Fig. 80.—Track Construction with Monolithic Reinforced Concrete at Nuremburg (Eisig System).

Fig. 81.—Half Cross-section of Street-railway Track Construction at Paris, France.

while at Geneva the rail sets upon a chair, which itself rests upon a steel tie. Nearly all the types shown have some distinct characteristic or peculiarity.

CHAPTER XV.

WIDTH OF STREETS AND ROADWAYS, CURBING, SIDEWALKS, GRADES, ETC.

WHAT has been said in these pages heretofore has had special reference to that portion of the street between the curbs and wholly in regard to use, not taking into consideration the general appearance of the street. The space between the curb and the property line, however, has as much to do with the general effect of the street, especially in villages and suburbs, as the pavement itself.

What is the proper width of streets has been an open question for many years, and it cannot be definitely settled as a rule, but the width must be governed by special conditions in each case. The east and west streets of New York City generally are 60 feet wide, while the avenues running north and south are 100 feet wide. In Brooklyn the width varies from 40 to 100 feet according to locality. In Omaha, Neb., the streets in the original city plat were 100 feet wide, with two streets leading from the capitol 120 feet wide. Macon, Ga., probably has the widest streets of any city in the country, those running in one direction being alternately 120 feet and 180 feet wide. These widths are extreme and, while adding greatly to the beauty of the city, are expensive when they require paving, and inconvenient in the business part of the city.

Broad Street, Newark, N. J., is 132 feet wide, with a 92-foot paved roadway.

The distance between the curbs must be established according to the width of the street, the amount of traffic, and whether the roadway is to be occupied by street-car tracks. Different cities have different principles for establishing these widths; some having a general rule that applies to all streets, others establish an arbitrary roadway for streets of different widths.

In the old city of Brooklyn, N. Y., streets 50 feet wide had a roadway of 24 feet, those 60 feet wide a roadway of 30 feet, those 70 feet wide a roadway of 34 feet, those 80 feet wide a roadway of 42 feet, and those 100 feet wide a roadway of 60 feet.

In New York City the roadway of a street 60 feet wide is 30 feet. In St. Louis a street 60 feet wide has a roadway of 36 feet. Omaha and some cities of Europe establish the width of roadway as equal to three-fifths of the entire width of the street.

While it is well, perhaps, to establish these widths arbitrarily, it will often be found best to modify the rules according to special conditions in many cases. On a business street a roadway should be made of such a width as will accommodate traffic, unless by so doing the sidewalk space is too much restricted. When car-tracks exist on such a street the space between the track and curb should be of sufficient width to allow teams to pass between the car and another team standing by the curb. To accomplish this would require a width of roadway of about 44 feet. If this width cannot be obtained without making the sidewalks too narrow, but one track should be allowed on the roadway, the cars making their return-trip on another street. This plan has been adopted for Philadelphia where the roadways of the streets are very narrow.

A street 70 feet wide would allow the above space of 44 feet for the roadway and leave 13 feet on each side for sidewalks. In cities of ordinary size this would be sufficient, and having a street of that width, such an arrangement would give good satisfaction. In the residence portion of the city such width is not necessary and perhaps not desirable. It has been customary in most cities, especially where the property is built up in solid blocks on the street-line, to allow a certain amount of space adjoining the property to be used and fenced in by citizens as a courtyard. This allows the building to be constructed on the property-line and have a small amount of yard-space in front. Where houses are built with basements this is almost absolutely necessary. As the extra width of the street over what is necessary for roadway, street, and sidewalk travel is only required to give light and air, such use can do no harm.

The original practice in laying out roadways of streets was to make them wide, and in most cases wider than necessary. Before

the time of pavements this was not so objectionable; but when the street comes to be improved, any portion that is paved over and above what is necessary for the convenience and use of the travelling public is wasted and can better be used for the adornment of the street.

As a general rule, it can be laid down that the width of 30 feet between curbs is sufficient for the ordinary residence street. When a street or avenue, however, is or becomes a great artery of travel, so that it receives abnormal traffic, then the width should be increased. A great many streets in Brooklyn, N. Y., are only 34 feet wide between curbs, and have on them a double line of street-car tracks. This leaves a space of only 9½ feet between the tracks and curb. This seems small, but when the street is paved with smooth pavement and the street-car tracks are properly constructed it serves very well in the ordinary residence street.

Where streets are of great width, as in some of those previously cited, parks are often laid out in the centre of the street, thus reducing the amount of area to be paved and at the same time adding very much to the general appearance of the street and city. In the 180-foot streets of Macon before mentioned, the space was divided up into 15 feet for sidewalk, a 50-foot roadway, a park 50 feet wide in the centre, another 50-foot roadway, and the other sidewalk, 15 feet wide. These parks were set out with live-oak trees and added very much to the beauty of the city; but even with that arrangement it left a space 100 feet wide to be paved. Many of the streets and parkways of Boston, Baltimore, and other cities are laid out in this way.

Ocean Parkway in Brooklyn, which extends from Prospect Park to Coney Island and is the popular and fashionable drive of the city, is 210 feet wide, divided up as follows: Sidewalk, 15 feet; roadway for heavy traffic, 25 feet; park, 30 feet wide; roadway, 70 feet wide; another park, 30 feet wide; another driveway for heavy traffic in the opposite direction from the first, 25 feet wide; another sidewalk, 15 feet wide. This boulevard has at its upper end eight rows of trees and presents a very fine appearance.

The following ordinance of the Board of Estimate and Apportionment, City of New York, governs roadway widths in that city, modified slightly for the Borough of the Bronx.

Resolved, That unless otherwise provided by franchise or by a special resolution of this Board, the following rules shall apply to all streets which may hereafter be improved within the limits of The City of New York:

1. The roadway width of streets shall be such as to give a clear space between curb lines as follows:

(*a*) For streets less than 20 feet wide and used for vehicular traffic, the width of the roadway shall correspond with the street width, less the space occupied by the curb.

(*b*) For streets having a width ranging from 20 feet to 50 feet and not occupied by a railroad, the width of the roadway shall be 60 per cent of the total width of the street.

(*c*) For streets having a width ranging from 50 feet to 60 feet and not occupied by a double-track railroad, the roadway shall have a width of 30 feet.

(*d*) For streets having a width ranging from 60 feet to 66 feet 8 inches and not occupied by a double-track railroad, the width of the roadway shall be one-half of the total width of the street.

(*e*) For all streets having a width of over 66 feet 8 inches, except those portions of Fifth Avenue and of Forty-second Street, Borough of Manhattan, concerning the treatment of which a resolution was adopted by this Board on December 18, 1908, the roadway width shall be 80 per cent of the street width less 20 feet, provided, however, that if the street is occupied by a double-track railroad the minimum roadway width herein prescribed for such railroad shall be required.

(*f*) For streets in which there is a single-track railroad, the minimum roadway width is to be 30 feet.

(*g*) For streets in which there is a double-track railroad the minimum roadway width is to be 40 feet.

2. The curb corners at street intersections where the interior angle is 30 degrees or more, shall be turned with a curve having a radius of 5, 6, 8, 10 or 12 feet, this being determined for each case as the nearest of these dimensions which would represent 10 per cent of the width of the wider street, provided, however, that in case the interior angle is less than 80 degrees the radius shall not be less than 20 per cent of the distance between the

building line corner and the point of intersection of the curb tangents.

For intersections where the interior angle is less than 30 degrees a tangent shall be inserted in the curb line at the corner at right angles to the line bisecting the said interior angle, and at a distance from the building l'ne corner equivalent to the width of the wider sidewalk of the intersecting streets, the said distance being meas-used along the bisecting line. The curves to connect this tangent with the curb lines otherwise provided for, shall each have a radius of 6 feet.

3. The roadway shall be centrally located between the street lines, and for streets having a width of 20 feet or more the remaining space on each side of the roadway shall be designated as the sidewalk.

4. No encroachment shall be permitted upon any roadway unless authorized by a franchise.

5. No encroachment of a permanent nature shall be permitted upon the sidewalk space of streets owned in fee, or shall be hereinafter permitted upon an easement street between the elevation of the curb and a horizontal plane 10 feet above the elevation of the curb.

Having settled upon the amount of space to be left between the curb-line and private property, it remains to determine how this shall be treated. An ordinance governing the widths of courtyards in the old city of Brooklyn provided that they should be one-twelfth the width of the street, but not to exceed 5 feet. A street 70 feet wide having a roadway 34 feet in width allows a sidewalk-space of 18 feet on each side; deducting from this 5 feet for the courtyard, there is left a space of 13 feet to be treated.

The best and probably the most economical method of treating this space would be laying a sidewalk 8 feet wide next to the court-yard, leaving a space of 5 feet adjacent to the curb, the sidewalk being extended to the curb opposite every house to give access to carriages. The remaining space could then be sodded and would give ample room for the planting of trees, than which nothing adds more to the beauty of any city.

In smaller cities and in the suburbs of large ones where detached houses are built and set well back from the street-line,

courtyards are not necessary, but the location of sidewalk given above would be satisfactory. In some localities, however, it might be as well to reduce the width of sidewalk, but in any event it should not be allowed to be decreased beyond 5 feet.

Some people advocate the laying of the sidewalk next to the curb. This plan, while sometimes adopted, does not give as good satisfaction as the one proposed, and compels the trees to be set back at a considerable distance from the curb. Ocean Avenue, Brooklyn, is 100 feet wide in the best residential section of the suburbs of Brooklyn, and was recently improved and a sidewalk laid 8 feet wide next to the curb. This was considered best, not because the most desirable location for the walk, but if located further from the curb it would have destroyed a great many fine trees that had already attained considerable growth on a portion of the street, and the desire to have the improvement uniform led to the adoption of the plan described.

Curbing.

The curb of the street adds very much to its general appearance. It is practically placing the frame around the picture. It acts, too, as one side of the gutter and serves to protect the sidewalk-space from the wheels of carriages and delivery-wagons. Curbing is generally made of granite, sandstone, limestone, and Portland-cement concrete, and sometimes even wood. This latter material is extremely temporary and is so seldom used that it cannot be strictly considered curbing material.

Dimensions.—In making specifications for curbing, the maximum and minimum of length is generally specified. If the stones be too short, the joints are frequent and the general appearance of the street thereby injured. If they are too long, they are handled and set with difficulty and seldom get a firm bearing in their bed and are consequently very easily broken. Their depth depends very much upon the material and manner in which they are set. The extremes are from 8 to 30 inches, although most cities specify a depth of from 18 to 20 and a few 24 inches. If the street is to be paved with asphalt or brick and curb set in concrete, there is no necessity of making the depth more than 16 inches, as the concrete

practically becomes a part of the curb as far as its stability is concerned, and the firm, solid pavement in front keeps the curb absolutely in position.

With stone pavements, while the blocks run 6 and 8 inches in depth, a deeper curb may be required. In determining the thickness of the curb, consideration should be given to its appearance as well as its usefulness. In a residence street a curb 4 inches thick would perhaps be as wide as would be necessary for use, but its appearance, especially if the roadway should be wide, would be bad, and the usual practice is to make the minimum width 5 inches. On a business street where heavy trucks are liable to be backed up against the curb, a heavier stone is required and one 6 or 7 inches thick is generally used.

On some streets in Boston a granite curb is seen 12 and even 18 inches thick. This latter is, however, extreme, and in such cases the stone can be more properly considered as a coping-stone for the area wall than as curbing.

Material.—The exact material that should be used for curbing depends much upon the availability of any particular stone. For a business street granite is unquestionably the best. It presents a good appearance even when roughly dressed, and will withstand the blows which it receives from heavy trucks. While often expensive in some cities, in others it is perhaps as often the cheapest and most available material. In cities near granite-quarries, and where the cost of transportation is light, it is very generally used. While prices vary according to the times, locality, and condition, it was stated by the City Engineer of Albany that granite curbing in that city in 1897 cost, set, 39 cents per lineal foot for straight curb, and in 1898 52½ cents per lineal foot. Very few cities, however, can get this material for that price. These stones were 6 inches thick and 12 inches deep.

Hudson River bluestone, which is found in such great quantities in eastern New York, has been used to a great extent in New York, Brooklyn, and other neighboring cities. It is hard, durable, and, being stratified, is easily gotten out in any required dimension. In cities in western New York, and in Ohio, Medina as well as Berea sandstone has been used very successfully for curbing. The latter is soft when first gotten out and is easily cut, but hardens under the

action of the weather, and makes a very satisfactory material for residence streets. Colorado and other sandstones, as well as granite, is used in other cities of the West and South.

Dressing.—In specifying how curbing shall be cut, it is customary to designate it as 4-, 6-, or 8-axe work, as the case may be. This means in each case that the axe shall have that number of cutting edges per inch, that is, the axe-work is produced by dressing the stone with an axe that has six cutting edges per inch. In some portions of the country the softer stone is often dressed by machinery. Some engineers object to this, because ordinary curbing is liable to be chipped by traffic, and, if too smooth, at first any defect will show very plainly in contrast with the smooth surface. This, however, does not seem to be a valid objection, as instances of injury are so rare that it hardly seems that too smooth face or head of the curb could be objected to. Granite, however, does not require a smooth surface to give it a good appearance.

Setting.—Curbing is generally set with a slight batter, so that it is necessary to cut the head at such an angle to the face that even if the stone be set with a batter the face will still slope toward the outer edge.

With stone that does not break squarely, as much trouble comes from the joints, perhaps, as from any other source. Hudson River stone spalls off under the hammer and often leaves large re-entrant holes at the end, so that the curb when set, although coming close together at the top, a few inches down shows a wide joint. While no requirements should be made that will unduly increase the cost of the work, such joints should not be allowed. If the curb be set in concrete, the joints should be made tight, as far down at least as the concrete, although it is not necessary to have them full to the entire depth of the stone.

Radius of Curb at Corners.—Engineers vary greatly in their practice as to the radii used at curb-corners. Curved stone costs more per foot than straight. Consequently the less amount of curved work required, the cheaper it will be obtained. The minimum radius that has been used is 2 feet, and this could be obtained in one stone, so that the total length of curved curb at the right-angled corner was practically 3 feet. This is an extreme case and should only be used where the cost of curved stone is ex-

treme and the appropriation for the work small. By increasing the radius to 4 feet the corners can be gotten out in two stones of the same length and can be cut from much smaller stones.

The general practice is to make the radius from 6 to 12 feet. Too large a radius requires a great amount of curved stone to be used, and the curbing when set, although making a good appearance and being easy for vehicular travel, is inconvenient for pedestrians on the sidewalk, as, if two or more persons be walking abreast, the one nearest the roadway reaches the curb considerably sooner than the one on the other side and awkwardness ensues. In Brooklyn, N. Y., a radius of 6 feet was used for a considerable time and gradually increased to 12 feet. This, however, was considered excessive, and in 1898 the following requirement was adopted in the Department of Highways of Brooklyn, New York:

"On all street-corners where angles between intersecting curbs are more than 80° and less than 100° the corners having a radius of 9 feet shall be used, and where the interior angle formed of intersecting curbs is less than 80° the curbs having a radius of 12 feet shall be used, and when the interior angle is greater than 100° a radius of 6 feet shall be used."

The present rule has been given in the ordinance of the Board of Estimate and Apportionment.

Specifications for curbing in different cities do not, as a rule, specify what radius will be required, but provide that the curbs shall be set at all corners cut to such a radius as the City Engineer may require.

Foundation.—The early practice, and in fact down to within comparatively few years, was to set the curb either upon the natural soil of the street or a foundation of sand or gravel. This artificial foundation was necessary in order to have the stone firmly bedded, and also to provide drainage. In naturally sandy soils this moisture provision is not required. Some engineers, where the earth is clayey, lay drain-tiles under the curb and connect them with a catch-basin in order to drain the soil and prevent its heaving and displacing the curb by the action of the frost.

At the present time, when improved pavements with concrete base have come into such general use, it has been found more satisfactory to set the curbing in concrete. This allows the curb to

be set in place with the knowledge that it will be maintained in this position permanently, and insures a good pleasing appearance and also a more durable curb, as, if kept in position, it will be subject to very much less wear than it otherwise would. Figures 82 and

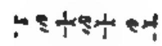


FIG. 82.

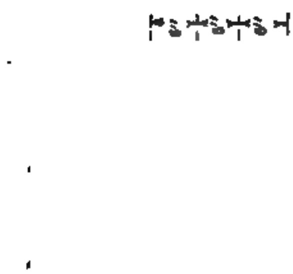


FIG. 83.

83 show curbs of different depth as set in concrete. The extra amount of concrete required, as shown in these figures, is practically 1 cubic foot for a 16-inch curb, and 1½ cubic feet for a curb 20 inches in depth. In setting a curb, some engineers require also that the stone should be kept apart at the end by the insertion of a metal shim or piece of hoop-iron. The object of this is to prevent the spalling off of the end of the curbs if they should settle. This, however, seems to be a useless requirement, as observation of a great many miles of curbing, set stone to stone, has shown but a very small percentage of any joints injured in this way. This is for a curb set on sand, and when used with a concrete base the

danger of any settlement is reduced to a minimum, and it is safe to require in all cases that the curb be set stone to stone at the end.

Limestone.—In some localities limestone has been used for curbing. This material, however, is not very well adapted for this work. It is liable to be too soft and is subject in many cases to the action of the water. If circumstances are such that limestone must be used for economical reasons, care should be taken to get the best that is available. Some limestones are as durable, as far as the action of the weather is concerned, as perhaps almost any other stone, but all are not. Some curbing made of limestone in Omaha, Neb., disintegrated, and as curbing had practically disappeared in about six years after it was set. Fortunately but little of this particular kind was used.

Specifications for Curbing.

The following specifications for curbing of different materials, in different cities, give a good idea of the requirements of the best practice:

Liverpool, Eng. First-class Specifications.

"Curbstones to be of syenite, straight or circular as required, 6 inches thick at top, 7 inches thick at 5 inches below, and not less than that thickness for the remainder of the depth. To be not less than 12 inches deep nor less than 3 feet in length; to be carefully dressed on top, 8 inches down face and 3 inches down back, the remainder of each stone to be hammer-dressed. The head joints to be neatly and accurately squared throughout the entire depth."

Cincinnati, O.

"The minimum length of curbing will be five (5) feet except for closures, or for curved corners, where the length will be fixed by the Engineer, but will in no case be less than three (3) feet, excepting where in special cases a shorter piece may be considered necessary by the Engineer. The bottom length will not be less than nine-tenths of the top length.

"The curbing shall be uniformly five (5) inches thick between

neat lines at the top and not less than four (4) nor more than seven (7) inches thick at any point.

"The depth of the curbing will be sixteen (16) inches with an allowable variation of not over one (1) inch either way. The top will be dressed with a rise of one-fourth (¼) inch from face to back. The front edge will be dressed to a curve of one-half (½) inch radius; the back edge will be neatly pitched to a true line parallel to front edge.

"The top and the face of curb for a depth of eight (8) inches shall be true planes and shall be pean-hammer dressed to show no projection exceeding one-eighth (⅛) inch and no depression exceeding one-fourth (¼) inch; below the eight (8) inches the face shall show no projections exceeding one-fourth (¼) inch and no depression exceeding three-fourths (¾) inch, the back will be dressed similar to face for a distance ef two (2) inches from top. The ends will be squared and dressed so as to afford close joints not exceeding three-sixteenths ($\frac{3}{16}$) inch for a distance of ten (10) inches from the top of the curbing."

St. Louis, Mo.

"All curbstones shall be of the best quality of granite. The curb shall have a straight face, rough pean-hammer-finish to an even surface on the side toward the roadway for the full depth of the stone, and pitched to line and rough-pointed on the side toward the sidewalk to a depth of 6 inches from top of curb, and shall have close end-joints to the full depth of the stone, and no stone shall be less than 4½ feet long, nor less than 6 inches thick, nor less than 16 inches deep. The curb shall be set on concrete 6 inches deep and 12 inches wide, backed with concrete 6 inches wide and 10 inches deep or 6 inches below the top of curb."

Borough of Manhattan, New York City.

"All curbstone is to be dressed and jointed before it is delivered upon the work.

"The bluestone curb shall be at least three and one-half (3½) feet in length and of one of the following classes in width and depth, as elsewhere specified:

Five (5) inches in width and sixteen (16) inches in depth.
Six (6) inches in width and sixteen (16) inches in depth.
Seven (7) inches in width and fourteen (14) inches in depth.
Eight (8) inches in width and fourteen (14) inches in depth.

"The granite curbstone shall be at least three and one-half ($3\frac{1}{2}$) feet in length and of one of the following classes in width and depth as elsewhere specified:

Six (6) inches in width and sixteen (16) inches in depth.
Seven (7) inches in width and fourteen (14) inches in depth.
Eight (8) inches in width and fourteen (14) inches in depth.
The surface of top and face shall be equal to good four-cut work.

"The Medina sandstone curb shall be at least three and one-half ($3\frac{1}{2}$) feet in length and of one of the following classes in width and depth, as elsewhere specified:

Five (5) inches in width and sixteen (16) inches in depth.
Six (6) inches in width and sixteen (16) inches in depth.
Seven (7) inches in width and fourteen (14) inches in depth.
Eight (8) inches in width and fourteen (14) inches in depth.

"The sandstone shall be of the best quality of Medina sandstone, free from quarry checks or cracks, and quarried from fine-grained live rock, showing a straight and even structure, and shall be of uniform quality and texture, free from seams or lines of clay.

"The face for a depth of nine (9) inches and the top on a bevel of one-tenth (1/10) of an inch for each inch in its width shall be dressed to a surface which shall be out of wind and shall have no depressions measuring more than one-quarter of an inch from a line or straight edge of the same length as the curbstone. The remainder of the face shall be free from projections of more than one-half an inch, and the back for three (3) inches down from the top shall have no projections greater than one-quarter of an inch measured from a plane at right angles to the top. The bottom of the curb shall be rough squared with a width of not less than sixty per cent (60%) of the top width.

"For the full width of the stone for a distance down of four (4) inches from the top, and there below for a width of one and one-half inches back from the face to a point twelve (12) inches below the top of the curb, the ends shall be squarely jointed with no depression greater than three-eighths of an inch, measured from a straight edge. Curved curb corners shall be cut with true radial joints and be set accurately to such a radius as may be required in three (3) foot lengths. It shall be paid for as straight curb and must comply in all respects with the above requirements therefor."

Rochester, N. Y.

"The new curbstone must be of the best quality of hard Medina sandstone of uniform color. The stone, including those in curves, shall be not less than 3 feet in length, inches thick, 18 inches deep, and matched width throughout. Top and arris shall be axed to a smooth surface with a bevel on top of $\frac{1}{4}$ inch, unless otherwise directed. Face of curb shall be dressed to a true surface, which shall in no place vary more than $\frac{1}{4}$ inch from a true plane for 12 inches down from the top. The price bid for new curbstone is for straight curb and an allowance of 40 per cent will be made for curved curb, cut to a radius less than 40 feet. The back shall be point-dressed for 3 inches down and hammer-dressed on the remainder of the surface. The bottom shall be roughed off parallel to the top and of full width, not less than 6 inches shorter than top. The faces shall be parallel and true to the line and curve to which it is laid. The ends for at least 12 inches down from the top shall be truly squared and dressed, so that when laid the end joints for the depth of 12 inches and full width of the stone shall not exceed $\frac{1}{4}$ inch."

Rochester sets its curb on concrete and lays a 3-inch drain-tile under the concrete foundation.

Concrete Curb.

In some sections of the country where stone of any kind is not available, curbing has been made artificially of Portland-cement concrete. This makes, when honestly laid, a substantial and

pleasing curb. With the great increase of the manufacture of Portland cement in this country this material can be had cheaply in nearly all sections, so that the artificial curb can compete successfully in price with the natural stone. It has been laid to a considerable extent in the West, and its use is being rapidly extended to eastern cities. While perhaps it will not stand the hammer and shock of heavy traffic as well as natural stone, it will give good satisfaction on residence streets. To obviate, however, as much as possible the damage liable to be caused by trucks, the corner of the curb has been protected in some instances by a steel rail as shown in Fig. 84. It makes a useful addition to the curb.

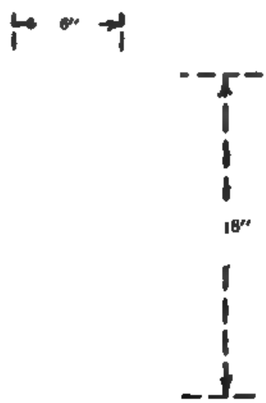


FIG. 84.

An additional price of 25 cents per lineal foot was charged for this steel corner on curbwork in Brooklyn in 1899. Considering the weight of the steel and extra labor of using it, this cost seems very excessive and should be reduced during the coming years.

In 1912, other methods had come into use and the cost had somewhat decreased.

Concrete Gutter.

Gutters of cement concrete are often used in connection with this curb on asphalt and macadam streets. Some contractors prefer to build the two combined in one piece, while others build

the curb first and, before the concrete is entirely set, construct the gutter, making only a partial bond with the curb, so that any heaving on account of frost will be taken up by the joints, where otherwise it might break the body of the concrete.

Where this gutter is used for macadam, and the subgrade of the street is soft, precaution must be taken to prevent the gutter from being lifted up out of position by the roller being used close to the edge of the gutter. In one or two instances the gutter was badly cracked and lifted in this way on several Brooklyn streets. This trouble was obviated by laying a plank 9 inches deep next to the edge of the gutter and extending 6 inches below it, thus preventing the earth from being forced under the gutter and lifting it. Specifications for this curb and gutter on Ocean Avenue were as follows:

"Curb and gutter shall be made in lengths not exceeding twenty feet with joints for the full depth of curb and gutter. The concrete, except for one inch immediately next to the top surface of face of the curb and gutter, shall be made of one part of the best quality of Portland cement, two parts pure, clean, sharp sand, and four parts clean broken stone. The sand shall be carefully screened and free from loam or other foreign material. The stone used shall be broken trap-rock or granite varying in size, none of which shall be more than one and one-half inches nor less than one-half inch in any direction, and it must be free from dust or dirt. The second or finishing course covering the top surface and face of curb of a thickness of not less than one inch shall be composed of one part of the best quality of Portland cement and one and one-half parts of finely crushed granite. This crushed stone shall be approximately cubical in shape, all perfectly fresh and clean, and of sizes from one-quarter inch downward, and must be free from dust. The cement and crushed stone shall be mixed dry, after which water shall be added and mortar worked into a thick uniform paste, which shall be laid on the first layer and trowelled and rubbed to a hard, smooth, uniform surface. The color of the concrete must be uniform in all cases and must be as nearly as possible the color of selected Hudson River bluestone, or similar in color to the sample of concrete in the Engineer's office."

Assuming a barrel of cement to contain 4 cubic feet of loose material according to experiments made in the laboratory of the Department of Highways in Brooklyn, referred to on page 133, it will require 1.7 barrels of cement, 0.5 cubic yard of sand, and 1 cubic yard of broken stone to make 1 cubic yard of concrete for the curb; and 1 barrel of cement and 6 cubic feet of crushed stone will make about 6 cubic feet of mortar.

Assuming the cost of Portland cement at $1.40 per barrel, sand at $1.30 per cubic yard, crushed stone at $2.00 per cubic yard, broken stone at $2.00 per cubic yard, the cost of one cubic yard of concrete and mortar will be as follows:

CONCRETE.

1 7-10 bbls. cement at $1.40	$2.38
½ cubic yard of sand at $1.30	.65
1 cubic yard of stone at $2.00	2.00
Total per cubic yard for material	5.03

Or 19 cents per cubic foot.

MORTAR.

4½ bbls. cement at $1.40	$6.30
1 cubic yard crushed stone at $2.00	2.00
Total per cubic yard for material	$8.30

Or 31 cents per cubic foot.

The quantity of material required to lay 200 lineal foot of curb is:

15 cubic feet of mortar at 31 cents	$4.65
161 cubic feet of concrete at 19 cents	30.59
Total	$35.24

And for 200 lineal feet of gutter there will be required:

33 cubic feet of mortar at 31 cents	$10.23
167 cubic feet of concrete at 19 cents	31.73
Total	$41.96

To lay 200 lineal feet of curb in one day it will take

1 carpenter	$4.50
1 helper	2.00
1 mason	4.50
8 helpers at $2.00	16.00
Total for labor	$27.00

Making the entire cost of 200 lineal feet of curb $62.24, or 31 cents per lineal foot. The carpenter and helper will be engaged in setting up and repairing the forms necessary for keeping the concrete in place, and to the above 31 cents should be added a small sum to pay for the lumber, the exact amount to be determined by the quantity of work, but it will be very small. No excavation is included in the above estimate.

To lay 200 lineal feet of gutter per day, constructed 2 feet wide and 6 inches thick, will take:

1 mason	$4.50
6 helpers at $2.00	12.00
Total	$16.00

Which added to the cost of material for gutter makes the total cost for 200 lineal feet of gutter $57.96, or 29 cents per lineal foot, making the total cost of the combined curb and gutter 60 cents per lineal foot.

These figures are given, not with the expectation that they will be exact for every locality, but to show the amount of material and labor required for a certain amount of construction. Any change necessary from the differences in the cost of labor or material from that given in the estimate can readily be made, but the quantities can be taken as correct.

The cost of stone curb varies greatly with localities and kinds of material. It has already been given for granite at Albany. In

Brooklyn, N. Y., the average price for bluestone, according to the specifications previously given, is from 75 to 80 cents per lineal foot. In other cities nearer quarries the prices are very much lower, so that the range can be safely said to be from 40 cents to $1 per lineal foot, according to location, material, and dimensions of the curb.

Sidewalks.

In the business and solidly built up residence portions of a city the sidewalks generally extend from the curb-line to the court-yard or property-line. When in a business section, as often happens, the area wall is built on the curb-line, the sidewalk is often made of a thickness strong enough to resist any transverse strain which it is liable to be subjected to, and often extends from the building-line to and resting upon the area wall, where it is made thick enough to act as a curb. This is technically termed "platform walk." In such cases the flags are often supported by double angle-irons running from the building to the area wall. The joints should be poured and calked with lead to prevent water from the street running into the area. Coal-holes are often cut through these walks, when a channel should be cut around on the upper side so that the surface- water will be drained from the hole to the gutter.

In suburban localities it is not necessary nor desirable that the walks should extend from the curb to the building-line. A walk 5 feet in width will allow two people to walk abreast comfortably, and one of 8 feet will permit passing; so that it would seem that a width of 8 feet would be sufficient for any suburban street, and that 5 feet should be adopted as the minimum.

Slope of Walk.—All walks must follow naturally the grade of the street. They all should be laid, too, with a slope from the property-line towards the curb, to allow water falling upon it to flow freely towards the gutter. Some little variation as to the amount of this slope exists in different cities. A fall of ¼ inch to the foot will be equal to a grade of 2 per cent. This will allow water to flow freely on the smooth surface, and will not be sufficiently steep to cause trouble from slipperiness.

The location of the sidewalk has previously been discussed.

Material.—The materials of which sidewalks have been constructed are wood, gravel, coal-tar, stone of different kinds, brick, and cement. The last three, however, are the only ones that are used to any great extent in cities for permanent walk. The construction of walks of wood and gravel is simple and need not be referred to. Coal-tar walks (or concrete, as they are often called) has been used to considerable extent in villages and smaller towns. Its use is subject to the same objections as that of the coal-tar pavement. It has, however, been very successfully used in small cities and villages.

In some cities of Europe, Paris especially, sidewalks have been laid with asphalt mastic. This is somewhat similar to the asphalt used in the pavement, but is much softer and is applied to the concrete base with a trowel in a manner very similar to cement mortar. The specifications require that the mastic shall contain not less than 15 nor more than 18 per cent of bitumen, and the sidewalk material must contain, by weight, bitumen-mastic 100 parts, bitumen for fluxing 6 parts, sand 60 parts. This material, however, has never been used to any great extent in this country.

Stone Sidewalks.

The exact character of the stone to be used in any locality will be determined to a great extent by its availability. Where very heavy stones are required granite is generally used, but it is expensive and wears smooth and slippery under traffic, so that, where laid on crowded business streets, it often has to be picked up and roughened to prevent its becoming too slippery. It has been used quite freely in business sections in Boston, New York, and other large cities where water-transportation can be had, but in New York almost all of the natural-stone sidewalks are laid with Hudson River bluestone.

Sizes of Stone.—The size of the individual stones laid in the walk should be determined principally by economical reasons. The larger the stones that can be used the better, as there will be fewer joints and less liability of the stones to be come uneven; but if the size be made too great, the cost will be excessive. It is more

expensive per square foot to quarry and transport large stones than small. There is also more liability of loss from breakages, so that care should be taken not to specify a size that will cause too great a cost.

If the minimum width of 5 feet be used, the stone should extend the entire width of the walk, and should contain at least 15 square feet, and it would perhaps be as satisfactory a plan as any to specify that no stone should contain less than a given number of square feet, according to the capabilities of the quarry from which the stone is to be obtained. It is sometimes desired, however, for other reasons than that of economy to cut the stone into smaller and regular pieces, often 18 or 20 inches square. This would be more expensive than in the larger sizes, but is adopted for appearance' sake. The stones in such cases should be set on a solid foundation and in the manner as shown in Fig. 85.

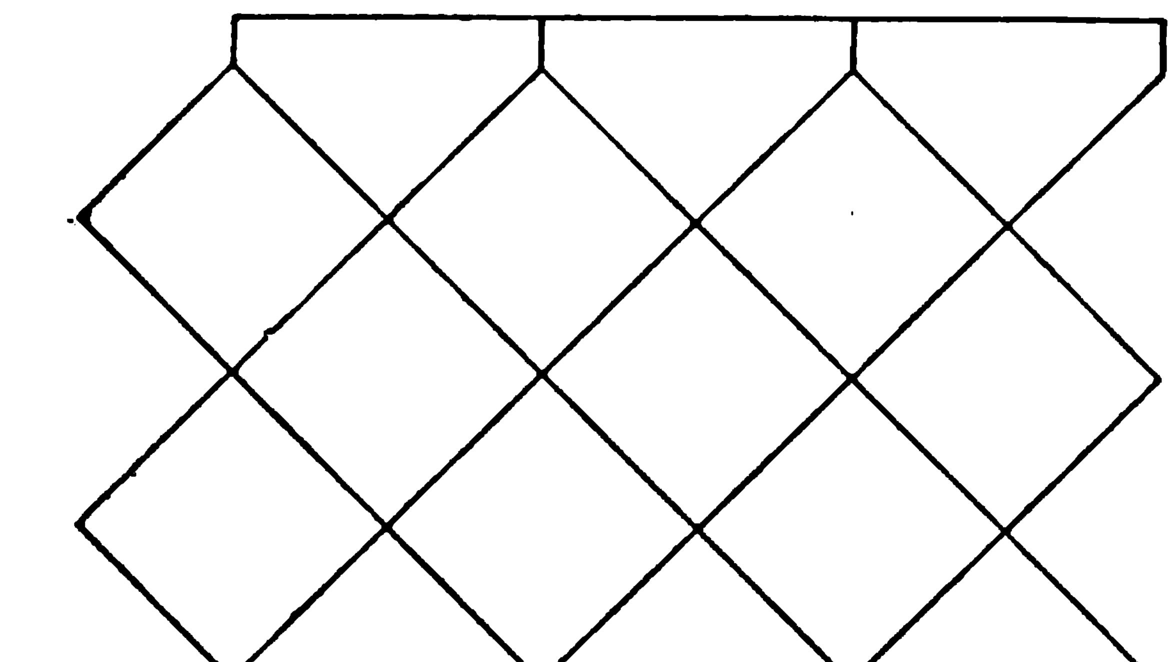


FIG. 85.

The thickness of the stone when laid on a sand base depends somewhat upon the character of the material, but for residence purposes 3 inches will perhaps be sufficiently thick. In business sections, however, where the walks will be subjected to having heavy articles dumped upon them from trucks, a greater thickness will be necessary.

Foundation.—This will depend somewhat upon the character of the soil, but ordinarily 6 inches of sand or steam-cinders will be sufficient for stone flagging.

Sandstones as a rule make the most satisfactory sidewalks. They are sufficiently hard to withstand wear satisfactorily, and their gritty nature prevents them from wearing smooth and slippery. Limestone, however, has been used with good success, especially that which comes from the quarries near Bedford, Ind.

Artificial Walks.

In sections of the country where stone is not available artificial material can generally be used to best advantage, and recourse is then had to brick and Portland cement.

Brick.—Brick has been used as a material for sidewalks for many years. The cities of Philadelphia and Boston probably have laid more brick walks than any others. The bricks are arranged in many ways, as shown in Figs. **86, 87, and 88**, according to individual

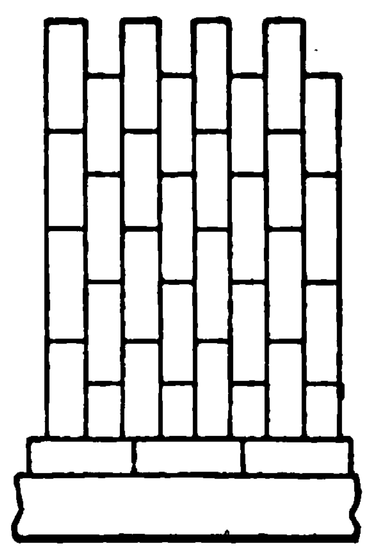


FIG. 86.

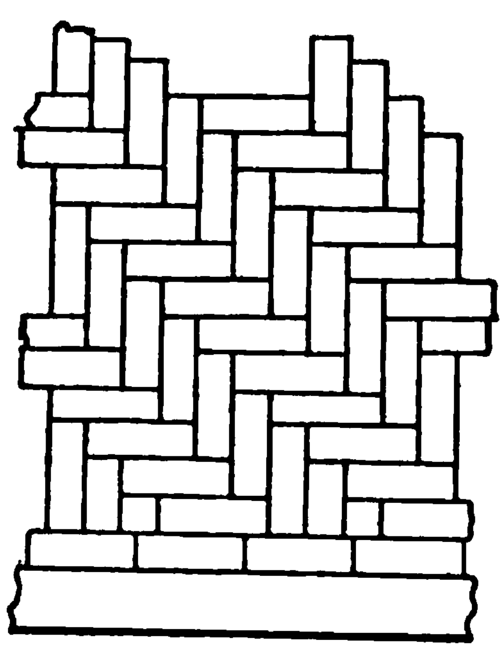


FIG. 87.

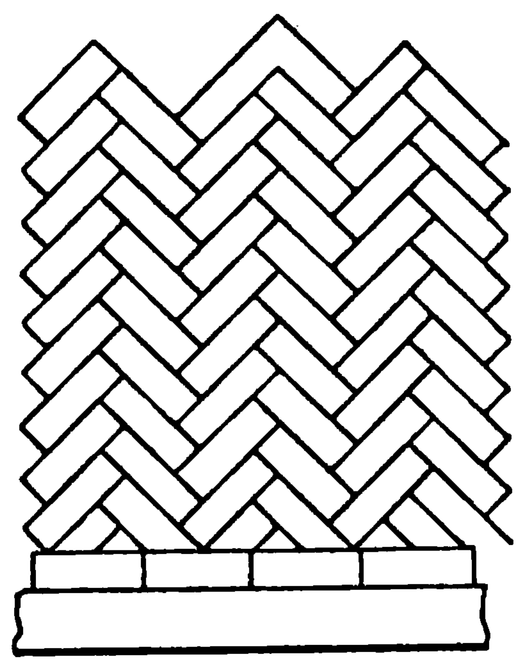


FIG. 88.

taste. They are generally of the ordinary building-brick size, but burned especially hard. They should be of an equal degree of hardness, so that all should wear evenly and prevent the surface from being rough. They should also be of uniform size and shape. As a rule, bricks are laid flatwise, but sometimes, where an especially solid walk is desired, they are laid on edge with cemented joints. The foundation is generally of sand, and the joints also

filled with sand. Special blocks are sometimes made of clay and burned for sidewalk purposes. When large these are often corrugated on top, so as not to be slippery. This plan has not been used to any great extent, as any broken or unfit material is almost a total loss, as it cannot be used to advantage in any other construction.

Cement Walks.—Within the past few years sidewalks made of Portland cement have come into use very largely, both in the larger eastern cities and those smaller ones of the West where stone cannot be had except at considerable expense. The walks are smooth, of pleasant appearance, and, when well constructed, durable. They must, however, like all construction of cement, be honestly and thoroughly built. Most of the failures of cement sidewalks are caused by the use of improper or too little cement, or on account of the work being performed by dishonest contractors. Cement walks are generally laid continuously, except that joints are made at frequent intervals to allow for expansion, so that any cracking which may be caused will be regular and at places prepared for it. In ordinary climates where the variation in temperature from summer to winter is not too great, lengths of 5 feet can be safely used without any danger of irregular cracking.

Small pieces of cement tiling are sometimes made and allowed to thoroughly set and harden before being laid in the walk. In such cases a foundation of concrete is prepared and then the tiles are laid upon the base and set in Portland-cement mortar. These tiles are made square, hexagonal, or octagonal in shape, and colored to suit the individual fancy. At the present time they are not used to any great extent, as most of the cement walks are laid practically in one sheet except as above described.

Specifications for such walk in Brooklyn provided for the concrete to be made as heretofore specified for concrete curb, and to be laid on 7 inches of clean steam-cinders which had been thoroughly rolled and tamped until they were solid and compact. The walk was laid in blocks 4 feet square, the joints being placed opposite the joints of the curb. In laying this walk after the concrete was in place, it was cut up into blocks 4 feet square by irons especially prepared for that purpose. Besides the base the walk consisted of 4 inches of concrete and 1 inch of mortar. The labor organization was as follows:

*6 masons at $4.50	$27.00
6 men tamping, at $2.00	12.00
14 men making concrete, at $2.00	28.00
3 men mixing surface mortar, at $2.00	6.00
4 men carrying surface mixture, at $2.00	2.00
4 laborers grading, providing water, etc., at $2.00	8.00
1 foreman	4.00
Total for labor	$87.00

This gang laid 2560 square feet of walk per day. The concrete-mixers also wheeled the concrete from the mixing-boards to the work. This amount of walk required the following amount of materials:

8 cubic yards of mortar, at $8.30	$66.40
32 cubic yards of concrete, at $5.03	160.96
71 cubic yards cinders, at $1.00	71.00
Total for material	$298.36
Labor	87.00
	$385.36

Or per square foot 15 cents.

The Philadelphia specifications for cement sidewalks require that the excavation shall be made 8 inches below the finished grade of the sidewalk. Upon this subbase shall be placed, and thoroughly rammed, 3 inches of gravel screenings, broken brick, broken stone or cinders. Upon this foundation shall be laid 3 inches of cement concrete made of one part of Portland cement and two parts of sand and broken stone of such size as will pass through a 1½-inch ring, and in such quantity that when solidly rammed and compacted free mortar shall appear upon the surface. Upon the concrete foundation shall be laid the wearing surface. This is 2 inches in thickness and composed of one part of imported Portland cement and two parts of crushed granite, free from dust, the largest particles of which will pass through a ½-inch sieve.

The following is extracted from the specifications of New York City relating to the construction of bluestone sidewalks:

"All new flagging shall be of bluestone of satisfactory and uniform color and equal in quality to the best North River blue-

* Prices changed for 1912.

stone, and shall be free from sap, seams, flaws, drill-holes, and discolorations. It shall have a smooth surface, be out of wind, and not less than three inches thick at any point, and shall be five feet in length and not less than three feet in width, except that wherever in sidewalks an old stone of superior dimensions is broken, but one new stone shall be put, which must be in length and width not less than the old stone. New flagstone of smaller size shall be furnished when directed by the Engineer, such stone to be of specification thickness and be used when necessary to match existing courses on walks already partly flagged, and in the closure course of such walks as are to be flagged for the full width.

"All stone shall be chisel-dressed with opposite sides parallel and adjacent sides at right angles, on the four edges a distance down of one inch from the top and at right angles thereto, and such dressing shall be entirely completed before said stone shall be placed on the bed prepared.

"Flagging shall be laid, so far as is practicable, in regular courses five feet in width, and shall be firmly and evenly bedded to the grade and pitch required on four inches of steam-ashes, clean, gritty earth or sand, free from clay or loam; the work to be brought to an even surface, with all joints close and thoroughly filled for their full depth with cement mortar composed of equal parts of the best quality of American Portland cement and clean, sharp sand, and left clean on the surface; but no more mortar shall be mixed at any one time than can be used within one-half an hour, nor shall any mortar be laid against any edge of a stone until the stone to abut thereagainst shall have been completely dressed ready for laying."

Gutters.

It often happens that a street is improved by grading, curbing, and guttering, without the laying of any pavement. In such cases the gutter is generally formed of the same shape as it would have been if the street was entirely paved, and of granite, Belgian block, vitrified brick, or cobblestone, as the case might require. Whatever material is used, it should be laid in the same manner and according to the same specifications as a stone pavement upon the same foundation.

Special gutters are also constructed for streets that are macadamized. These are of the same material as those just mentioned, and should be constructed in the same way. It sometimes happens, however, that a street is macadamized in the suburbs when it is not desired to go to the expense of setting a regular curbstone. In this event the gutter is built in the form shown in

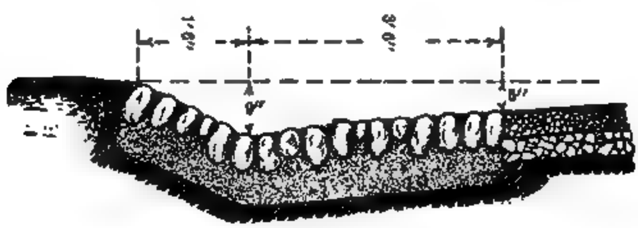


FIG. 89.

FIG. 90.

Fig. 89, the shoulder taking the place of a curb. Fig. 90 shows the form of cement gutter without curb as used in St. Louis.

Grades.

The gradient of paved streets is very important. The maximum varies greatly in different cities according to the local topography. In cities like Chicago the problem is to obtain sufficient grade for drainage; while in Duluth, Kansas City, and Omaha it is difficult to get a passable grade on many streets without excessive cuts and embankments. In the latter city one street was graded where a cut of sixty feet was made with fills even greater. Before the time of cable and electric street-cars a grade of 5 or 6 per cent was considered the limit for street-car streets,

but at the present time that element need not be made a ruling factor, though a much lighter grade is very desirable.

No arbitrary rule for a maximum grade can be laid down. But in a city that has been partially improved no grade should be established in excess of the maximum at that time in force unless absolutely necessary.

New York City has some grades as steep as 6 per cent on business streets, while in Brooklyn there are few in excess of 4 per cent. Pittsburg, Duluth, Omaha, and Kansas City are all examples of cities with excessive grades on paved streets.

The force required to draw a load up any grade can be easily ascertained by the following formula:

$$F = L\left(\frac{R}{100}\right) + T,$$

Where $F =$ force, $R =$ rise in 100 feet, $L =$ load, and $T =$ force required to draw L on a level surface. This, however, is theoretical and is based upon the supposition that the incline is absolutely regular and without friction.

When animal force is used to draw vehicles, the problem is different and the results cannot be calculated.

The ability of a horse to draw a load depends upon two things, his muscular force and his foothold upon the pavement. If the latter be such that he can exert all his power without slipping, he will be able to use his strength to the best advantage, and the weight of his load will be limited by his physical strength. If, on the other hand, the surface of the pavement be slippery, so that he maintains his foothold with difficulty, his available strength will be greatly reduced and his ability to stand up while exerting his strength will be the controlling factor. A horse, too, must carry himself in addition to his load, and as the rate of grade increases, a certain amount of his heretofore available power will be required to move himself, until finally a grade will be reached which he can barely climb with no load whatever. This stage could only be arrived at by experiment, and would vary greatly with the individual horse as well as the exact condition of each pavement. It would be useless, then, to attempt to estimate in exact figures the effect of grades upon vehicular travel when animal power is used.

It will be safe to assume, however, that a grade of 10 per cent will be prohibitive as far as heavy trucking in concerned.

In the report of the Commission of Highways of New York City for 1898 it is stated, quoting from a former report of the Consulting Engineer, that established grades of 10 per cent exist in that city upon a number of streets, and instances of grades of 12.17, 15.17, and one of 18.17 per cent are given. One clause says: "But the city of New York has apparently adopted a maximum grade for its thoroughfares of 18 per cent."

Pittsburg has grades of 17 per cent, Duluth 12.2 per cent, and Kansas City 16.5 per cent, all on paved streets, while one unpaved street in Pittsburg has a grade as steep as 30 per cent.

The importance of constructing the best pavement for these excessive grades can readily be understood. The two principal requisites are a smooth, unyielding surface and foothold for horses. Asphalt meets the first requirement, but not the second. The best results will be obtained by laying a block pavement of such material that it will not wear smooth or waste away under traffic. It must be remembered that loads drawn on excessive grades must necessarily be light as compared to the normal load, and that the wear will be due more to the action of the horses' feet than the abrasion of the wheels.

Hard sandstone or granite blocks from 3 to 3½ inches thick with smooth, even heads, laid with open joints filled with tar and gravel upon a concrete base, will give satisfactory results. Brick can also be used. It will not give quite as good a foothold for horses, but the traction will be less. Either of the above pavements would last a generation on most streets with grades of more than 10 per cent.

The practice of making the pavement rough on steep grades to give horses a better footing cannot be commended, as it increases so much the traction required to draw a given load. A rough stone pavement requiring a load to be lifted vertically over the stones may often cause the traction on a nominal 10 per cent grade to be equal to the normal traction of one of 15 per cent or even greater.

In establishing street-grades, the points specified in the ordinance differ in different cities. And in fact grades are sometimes

fixed simply by referring to an accompanying profile. This practice is very bad, as, if the profile is lost or becomes mislaid, the only record is that the grade has been changed. Whatever the instrument that makes the change, the figures of the new grade should appear on its face, so that if any record of the change remain, there shall be no question as to what it is.

It can be laid down as a fundamental principle that the elevations should be so fixed that there shall be no question in the mind of any engineer as to the established grade of any piece of property, its exact elevation being simply a mathematical calculation.

Grades in some cities are established by fixing the elevation of the streets at the centre of the intersections and at such points between the streets where it is desired to make a break in the grade. A strict interpretation of this would establish the elevation of the pavement only, leaving the curbs to be set according to the ideas of any engineer or surveyor who should happen to be called in to fix the curb-grades. On level surfaces or light slopes this would not be so objectionable, but on steep hillsides, where the prevailing grade is 4 per cent, there will be a difference of 1.2 feet between the elevation of the centre of the street opposite the two curbs of an intersecting street having a roadway 30 feet wide. And if the curb-elevations should be made the same, there would be an equal difference between the sides of the cross-streets which is excessive, and should not be allowed. The engineer then would be called upon to use his judgment and settle for himself the exact elevations of the curb-corners. Acting in this way in determining the building-grade for a piece of property situated midway of the block, it would be a coincidence merely if he should fix upon the exact elevation as finally determined when the street came to be improved. This is certainly a bad method. It is the curb-grade that fixes the grade at the building-line, and that is the only point that interests the property owner.

If, however, the elevation of each curb-corner, as well as all breaks in the grade, is defined by ordinance, there can be no misunderstanding, and the grade in front of all property may be definitely calculated.

If, however, the gradient much exceed 3 per cent, complications will often arise at the property-line corners.

Take, for instance, a case as illustrated in Fig. 91, where the

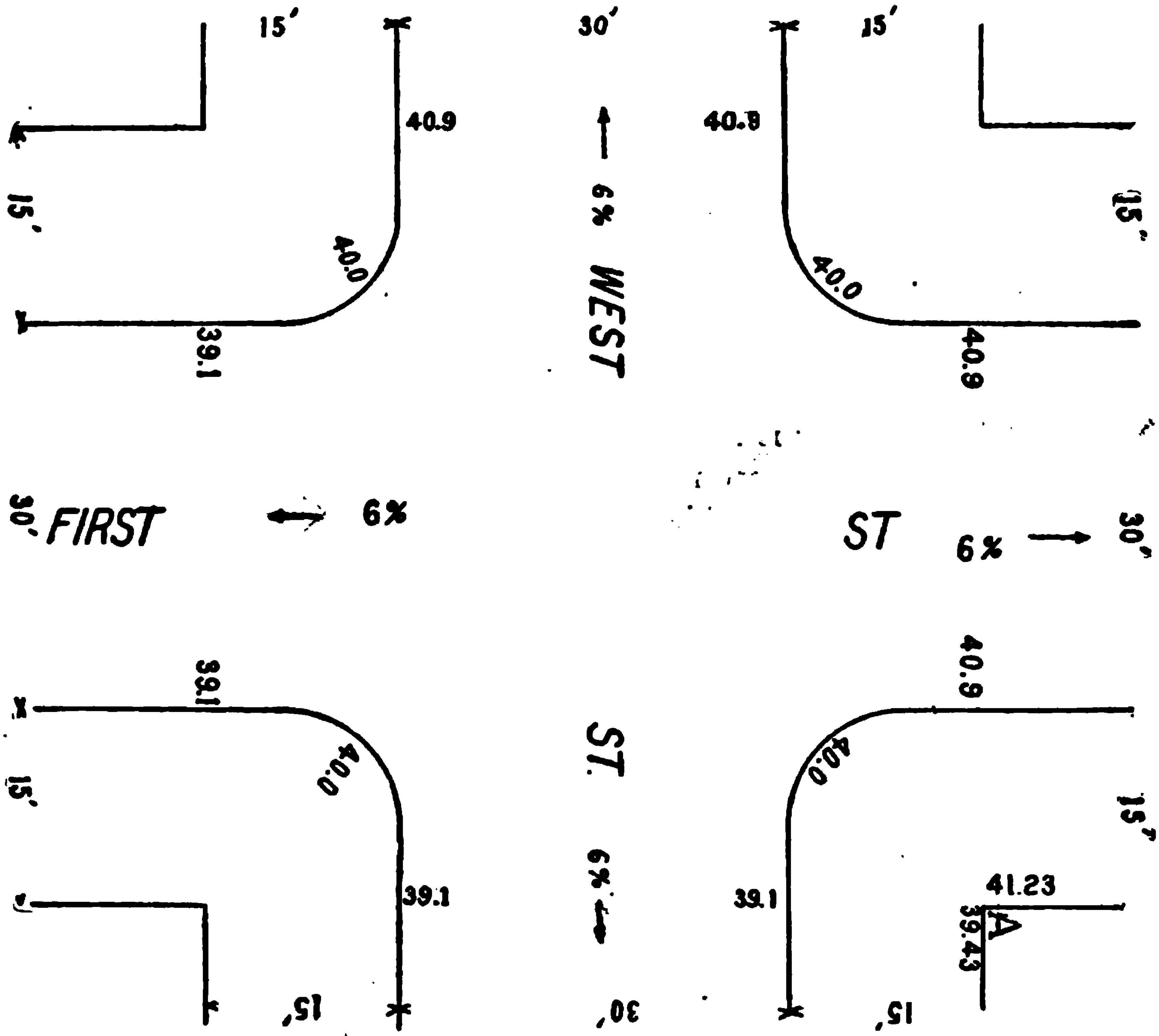


Fig. 91.

elevation at the curb-corners is 40.0 and the grades rise from the intersection in two directions at the rate of 6 per cent, and fall in the other direction at the same rate.

The elevation of the curb on West Street opposite the corner A will be 40.9, while on First Street opposite the same corner it will be 39.1, and the property-grade for the corner A as obtained from these elevations by adding .33, the standard sidewalk slope, will be 41.23 and 39.43 for the same point. This will create a great deal of trouble and confusion; especially if the street be un-

improved and the architect plans his building from the grade of the street upon which is the main entrance.

To overcome this a break of grade should be made at the property-line whenever the rate of grade exceeds 2 per cent. A grade of 2 per cent on an intersection insures a maximum difference of 0.6 at A when the sidewalk width is 15 feet as in the figure. When this width is more or less than 15 feet the rate of grade should be modified so that in no case shall there be a greater difference in property-line grades as calculated above than 0.6 of a foot. This difference can be reduced to a minimum by reducing the standard slope of the sidewalk on one side and increasing it on the other. On residence streets where buildings set back from the street this rule can be somewhat modified.

The following is recommended as a form for arranging curb-elevations in grade ordinances, the body of the ordinance specifying that the grade shall be a straight line between given points:

GRADE OF FIRST STREET.

	Elevation of East Curb.	Elevation of West Curb.
North curb of South West Street	22.0	22.0
South property-line of West Street	39.1	39.1
South curb-line of West Street	40.0	40.0
North curb-line of West Street	40.0	40.0
North property-line of West Street	40.9	40.9
A point 200 feet north of line of West Street	52.9	52.9
South property-line of North West Street	60.9	60.9
South curb-line of North West Street	61.2	61.2

The above method is satisfactory when the intersecting streets are at right angles to each other. When the lines vary from 90° trouble arises and the greater the variation the greater the trouble, especially if the grades are steep.

In a paper read before the Municipal Engineers of the City of New York, Mr. Vernon S. Moon, Asst. Engineer, Board of Estimate and Apportionment, presented some rules which if adopted would, it is believed, give satisfactory results and at the same time be positive and definite. It has been claimed that the

scheme is too complicated and elaborate, but the working out of the grades of an oblique intersection with steep slopes must be a complicated matter. Mr. Moon's plan is as follows:

1. *Definition of Platforms.*—The Center Line Intersection shall be deemed to be the point of intersection of the center lines, except for cases where the center lines do not meet at a common point, when it shall be the area included within the center lines at their intersection.

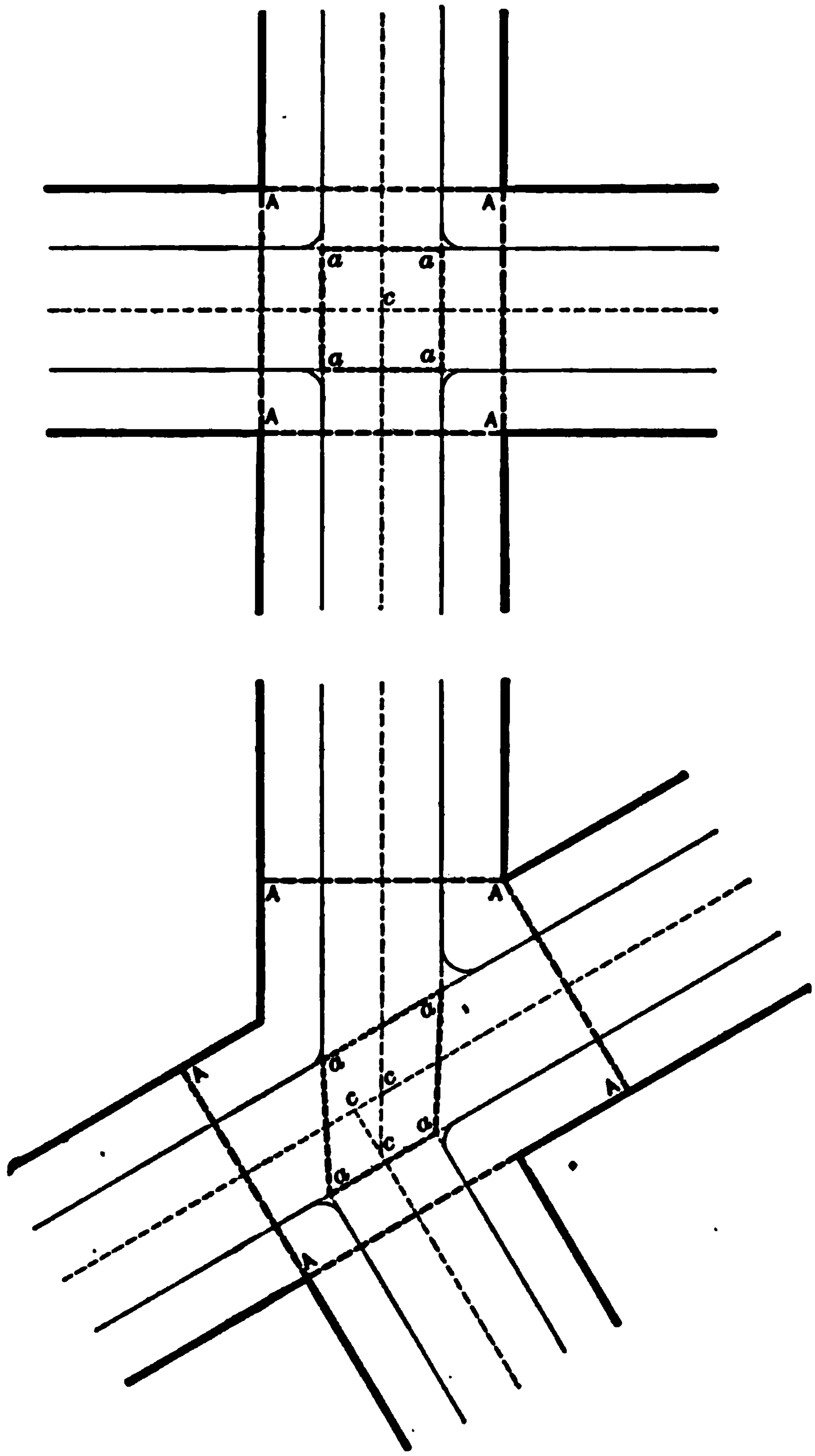
The Curb Line Platform shall be deemed to comprise the area included within the lines connecting the points of intersection of the curb tangents, or in the case of a street terminating at another street it shall comprise the area within the prolongations of the curb lines across the intersection and a line joining the curb tangents.

The Building Line Platform for rectangular intersections shall be deemed to include the area bounded by the prolongations of the building lines of both streets across the intersection so as to comprise the greatest platform area. In the case of other than right-angled intersections, it shall comprise the area bounded by the respective lines of each street and by lines at right angles or normal to the center lines and passing through acute-angled building line corners, or the corners giving the greatest platform area. If the intersection of the center lines falls without the Building Line Platform, as above described, the said platform shall be increased sufficiently to include the said intersection. When the building line corner is turned with a curve the platforms above defined shall be indicated upon the map unless herein definitely fixed.

2. *Definitions of Elevations Fixing Grades.*—Unless otherwise indicated on the map, the elevations shown at a street intersection shall be deemed to be that fixed for the point of intersection of the center lines of both streets affected, or for the Center Line Intersection.

3. *Treatment of Center Line Intersection.*—The Center Line Intersection, when it comprises an appreciable area and unless otherwise shown on the map, shall have a uniform elevation at its boundaries, and in determining the elevations for the other platforms herein described, the Center Line Intersection referred to

Established elevations and grades are indicated thus 32.5
Elevations and grades interpreted under the proposed rule indicated thus... 27.0



EXPLANATORY NOTE

Center Line Intersection indicated thus			*c* **and** *c,c,c*
Curb Line Platform	"	"	*a,a,a,a*
Building Line Platform	"	"	*A,A,A,A*

as a basis of calculation shall be deemed to be the nearest point on the center line of each street at the boundary of the said platform.

Curb Line Treatment.

4. *Treatment of Platform for Streets Having a L ght Grade.*—If the grade of each of the intersecting streets is 3% or less, as determined by calculating the rate between the established elevations, the elevation of the center lines of each street within the limits of the Curb Line Platform shall be the same as that fixed for the Center Line Intersection. The elevation of the curbs shall be determined as indicated in Paragraph 8. Provided, however, that the difference in the elevation of points on the center lines opposite any building line corner, shall not provide a greater transverse sidewalk slope than that fixed as the maximum in Paragraph 7, in which latter event the Building Line Platform shall be used and the grades of that portion of the streets adjoining the said corners shall be flattened between the boundaries of the Building Line Platform and the Center Line Intersection, as provided in Paragraph 5 (*a*).

Building Line Treatment.

5. *Treatment of Platform for Streets Having a Steep Grade or Meeting at an Acute-angled Intersection.*—(*a*) If the grade of any portion or portions of intersecting streets adjoining a building line corner is over 3%, as calculated between the established elevations, or if a further flattening of the platform grade is required to provide proper sidewalk slopes, for any part of an intersection described in Paragraph 4, the grades of the said portion or portions of each street shall be reduced between the boundaries of the Building Line Platform and the Center Line Intersection as follows: If the intersecting streets are of the same width, the grade of the street traversing the shorter block length adjoining the intersection shall be reduced one-third and that of the street traversing the longer block shall be reduced two-thirds. In case the streets have different widths, the grade of the wider street shall be reduced one-third and that of the narrower

street two-thirds between the above limits. All grades less than 3% which are not herein required to be flattened shall be applied at the same rate as originally computed between established elevations. Provided, that in no case shall the maximum platform and sidewalk slopes fixed in Paragraphs 6 and 7 be exceeded.

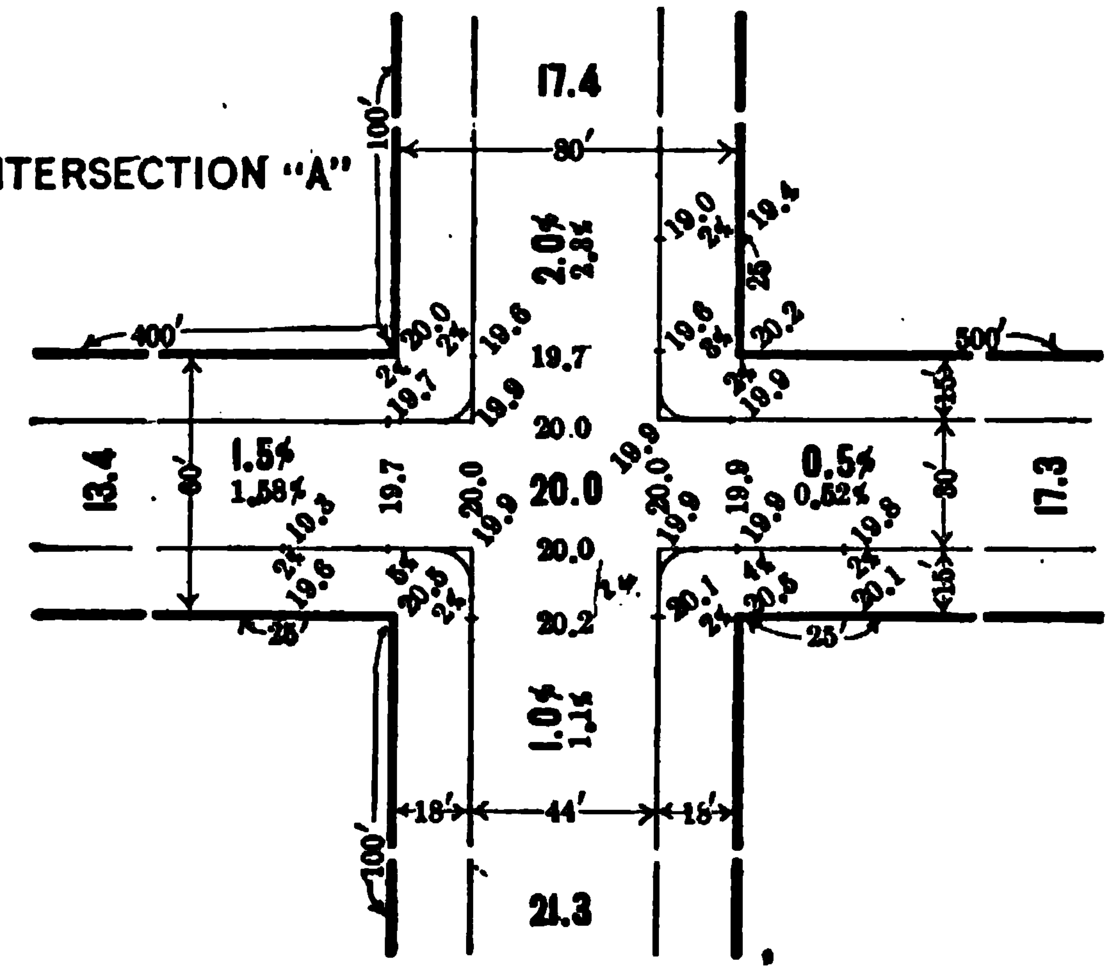
Any excess in grade over that allowed in Paragraph 7 shall be removed by further flattening, as follows:

(*b*) Special flattening of platform grades for extreme cases of steep grades or acute-angled intersections.—If the difference in elevation tentatively fixed for points on the center lines of intersecting streets opposite any building line corner, after applying the minimum and up to the maximum transverse sidewalk slope on the higher and lower sides respectively, exceeds the maximum transverse sidewalk grades hereinbefore described, the elevation of each street at the boundary of the Building Line Platform shall be adjusted to remove the excess, the adjustment of each of the said elevations being directly proportional to the grade of each as originally flattened or applied.

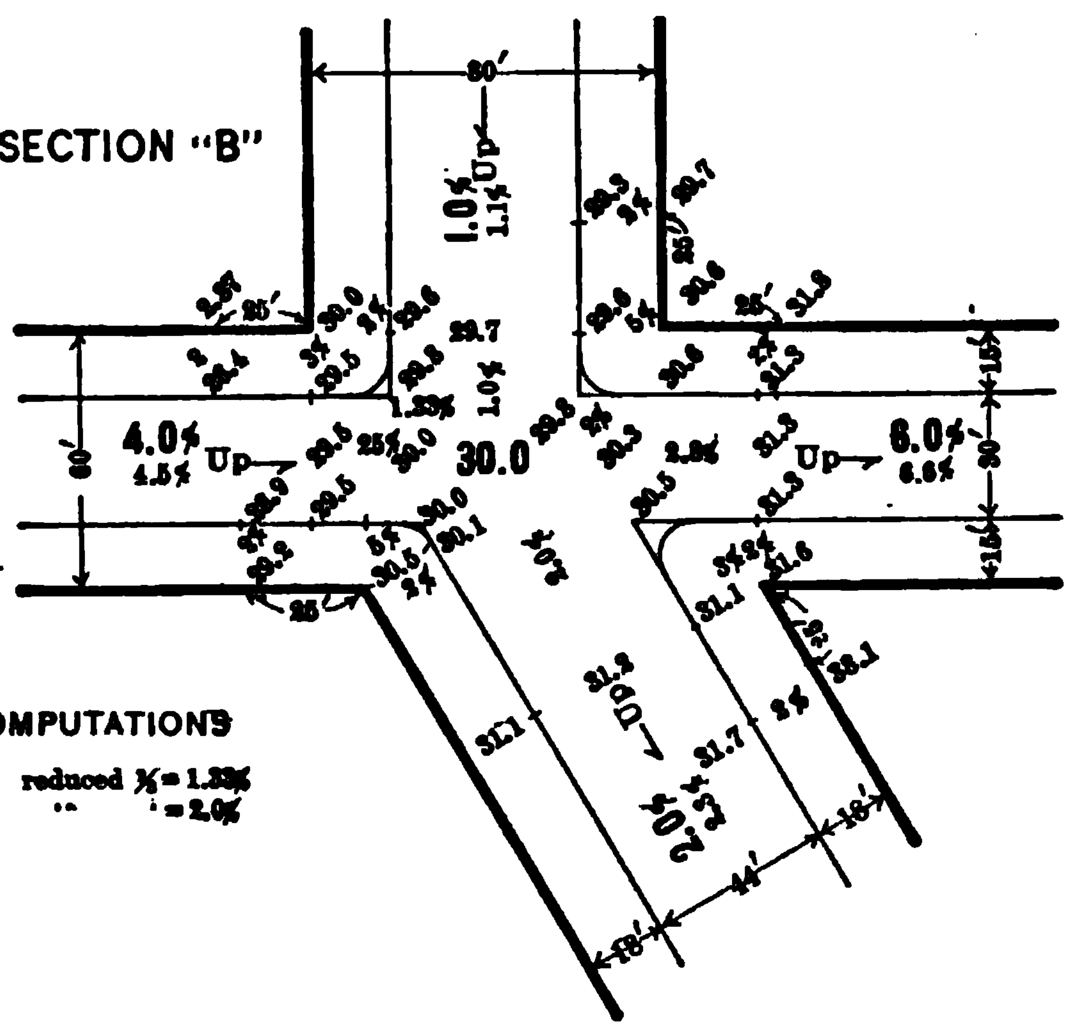
For all cases covered by Paragraphs (*a*) and (*b*) the elevations at the intersections of the center line of (each of the narrower streets or at the streets traversing the longer blocks, if they are of equal width,) with the Curb Line Platform of the intersected street shall be the same as the elevation of a point on the center line of the intersected street immediately opposite the first named intersection, except that the elevation at this point shall be abandoned when the grade along the center line between the Curb Line Platform and the Building Line Platform exceeds the grade as originally computed.

The grades of the center line of the wider street or of the street traversing the shorter block, if they are of equal width, shall be uniform between the exterior boundaries of the Building Line Platform and the Center Line Intersection, except that the maximum platform slope hereinafter fixed shall not be exceeded. The grades of the center line of the narrower street or of the street traversing the longer block, if they are of equal width, shall be uniform between the elevations fixed at the exterior boundaries of the Building Line Platform and those fixed at the boundaries of the

INTERSECTION "A"



INTERSECTION "B"

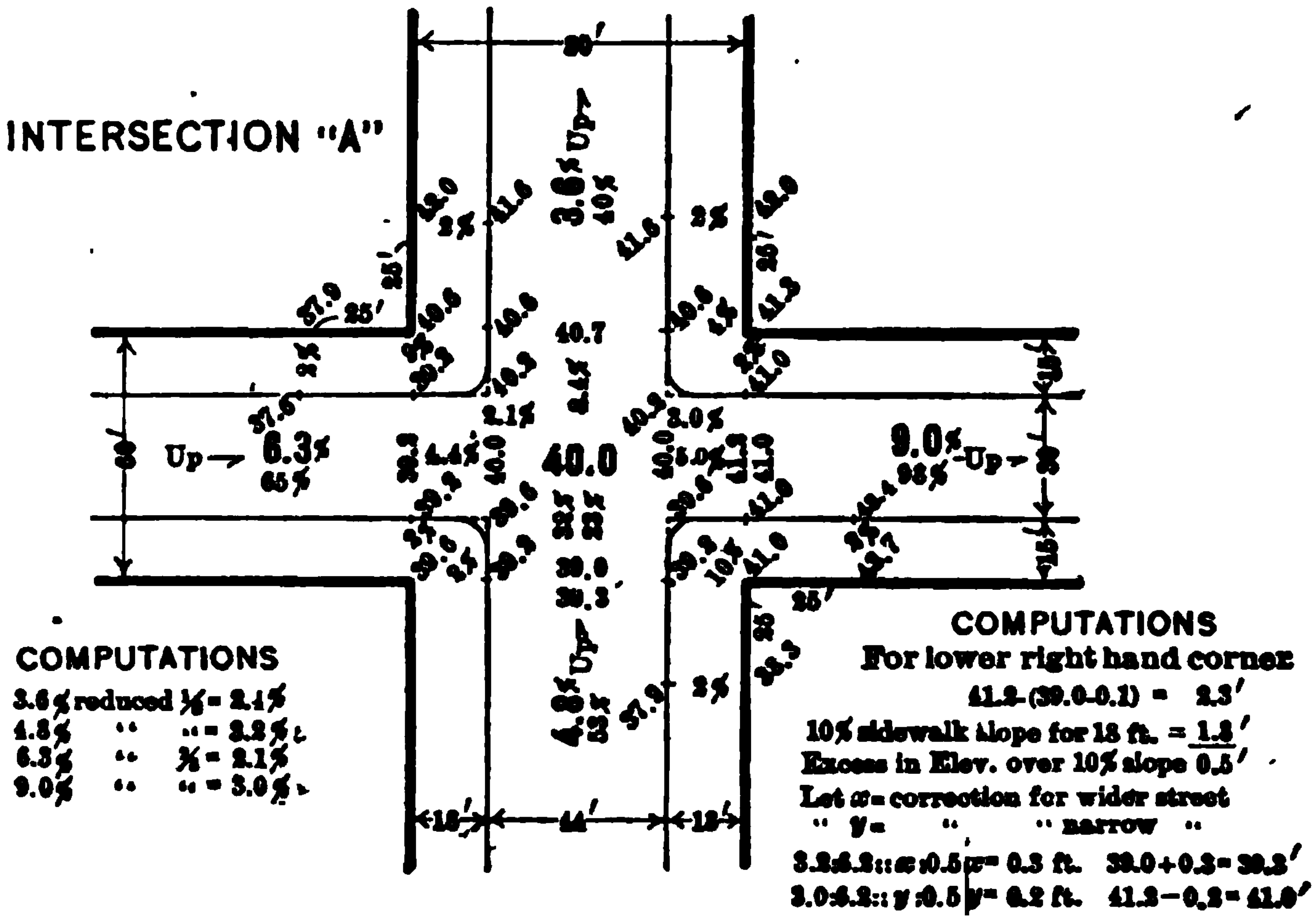


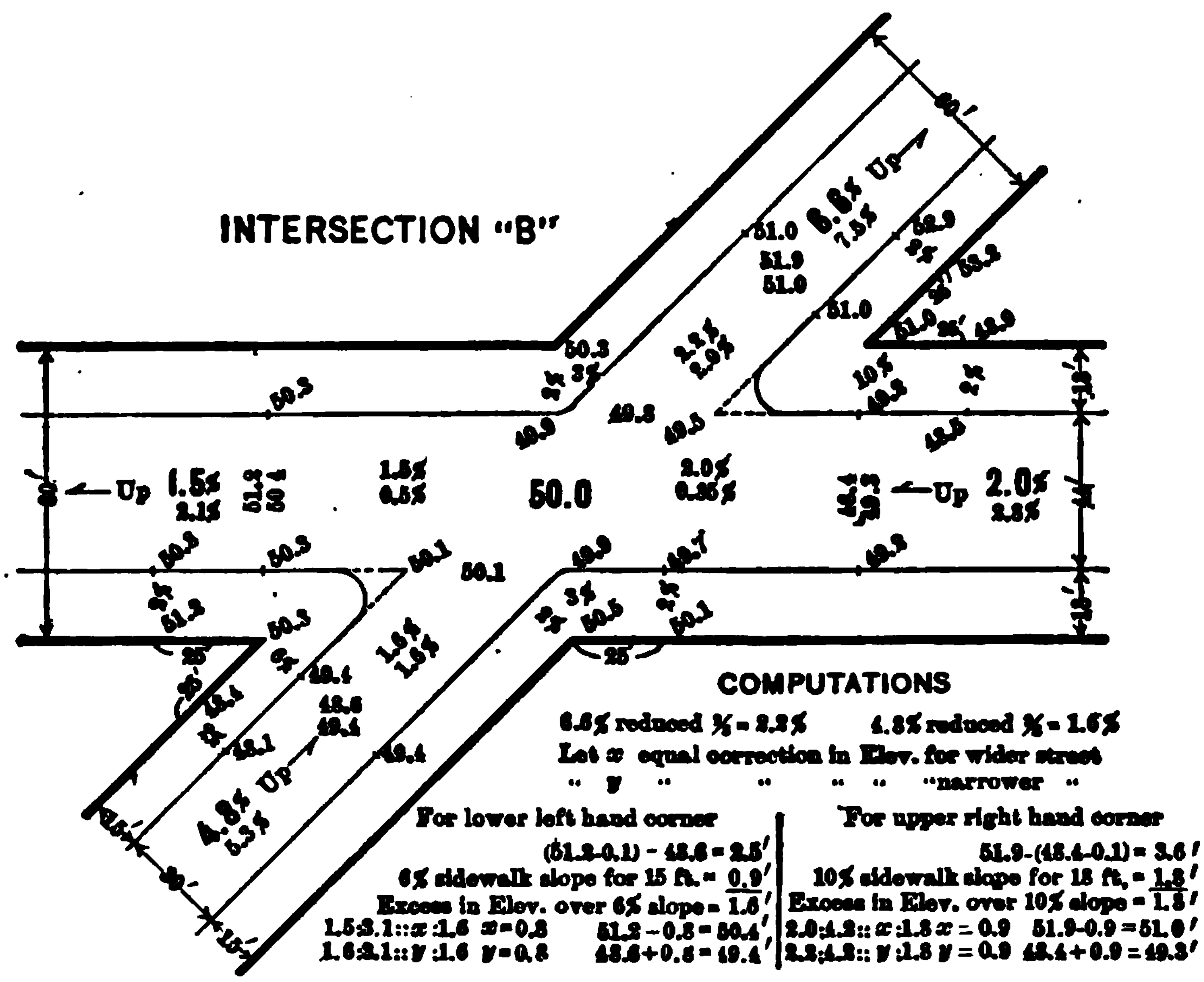
COMPUTATIONS
4.0% reduced ⅓ = 1.33%
6.0% " " = 2.0%

EXPLANATORY NOTE

Established elevations and grades are indicated thus **30.0**

Elevations and grades interpreted under the proposed rule indicated thus.... 31.8





EXPLANATORY NOTE:

Established elevations and grades are indicated thus ________ 50.0

Elevations and grades interpreted under the proposed rule indicated thus___50.8

Curb Line Platform, and also between the latter point and the Center Line Intersection.

6. *Maximum Platform Grades.*—The maximum allowable grade along the center line between the Curb Line Platform and the Center Line Intersection shall be at the rate of 4%, unless otherwise indicated on the map.

The grades along the center line between elevations established within the limits of a Building Line Platform shall be uniform, subject only to the flattening provided for in Paragraph 5 (*b*).

7. *Transverse Sidewalk Grades.*—Whenever practicable, the sidewalk shall slope upwards in a direction at right angles to the curb toward the building line at the rate of 2%.

The elevation of the sidewalk at the building line corner shall be determined by applying this rate to the elevation of the curb, giving the higher building line elevation, at a point immediately opposite the corner, unless the resulting grade on the lower side exceeds 6%, in which case the sidewalk shall be level on the higher side and a greater transverse sidewalk scope up to the maximum shall be used on the lower side.

The maximum transverse sidewalk slope shall be 6%, except in those cases where the street grade as originally computed on any street adjoining a building line corner is more than 6%, when the maximum slope shall be 10% for either street, opposite the said corner. In no case shall the sidewalk at the building line be lower than that of a point immediately opposite it on the curb.

If the transverse sidewalk slope at the building line corner is more or less than 2%, it shall be made to agree with this latter rate at a point distant 25 ft. from the building line corner.

8. *Curb Elevations.*—The relation between the elevation of the center lines and of the top of the curbs at points immediately opposite it at the boundary of and outwardly from the Building Line Platform shall be as follows: For roadway widths of 24 ft. or less the top of the curbs shall be 0.1 ft. higher than the center line. For roadway widths ranging from 24 ft. up to and including 34 ft. the top of the curbs and the center line shall be at the same elevation. For roadway widths ranging from 34 ft. up to and including 44 ft. the top of the curbs shall be 0.1 ft. lower

than the center line. For roadway widths ranging from 44 ft. up to and including 54 ft. the top of the curbs shall be 0.2 ft. lower than the center line, and for roadway widths ranging from 54 ft. up to and including 64 ft. the top of the curbs shall be 0.3 ft. lower than the center line.

The elevation of the intersection of the curb tangents shall be determined from a point immediately opposite on the center line of the wider street or the street traversing the shorter block, if they are of equal width, subject, however, to the same correction in elevation between the top of the curbs and the center line as herein provided.

9. *Depth of Gutters.*—Whenever practicable a standard depth of gutter of 0.4 ft. shall be used.

10. *Curb Grades at Corners.*—The tangents in the curbs shall be graded uniformly between the elevations established for them at the boundaries of the Building Line Platform and at the intersection of the curb tangents. The curve formed in the curb joining the tangents shall follow a uniform grade between the elevations of the curb tangents at the points of curve.

11. *Grades between Platforms.*—The grades of the center line and of the curbs between the elevations computed at platform intersections, or between a platform and an intermediate established elevation, shall be uniform.

CHAPTER XVI.

ASPHALT PLANTS.

THE machinery used for the preparation of the asphalt mixture is technically termed the plant. Its province is to take the different materials and mix them in the proper proportions for the pavement, and the arrangement that will properly do this the most cheaply and expeditiously is the best.

When it is understood just what is required of the plant, it is simply a problem in mechanical engineering as to its exact design.

Like all machinery a large first cost means a small outlay for operation and maintenance. But some contractors prefer to carry out details by manual labor rather than by machinery, giving as a reason that it is less liable to cause delay and in the end is more economical. All details must be governed by circumstances and the conditions of each case.

Before taking up methods of construction, it will be well to discuss somewhat the capacity and location of the plant, the two being associated more or less, especially in cities that cannot be supplied from one location.

Capacity.

In cities of 150,000 or even 200,000 inhabitants there is no necessity for more than one plant from an economical standpoint. Where different companies are operating in the same city, each must have a plant of its own; but it is proposed to discuss the question with a view to providing for a community as economically as possible. At the present time many cities have asphalt plants both for pavement construction and repairs.

Winnipeg, Toronto and Montreal, Canada, have operated asphalt plants for some years, the two former laying quite an

amount of new pavements, especially Winnipeg. The principal cities in the United States that have had large plants in use for some time are Detroit, Borough of Brooklyn, New York City, and New Orleans. It has been plainly demonstrated that it is not only just as practicable for a city to repair its asphalt pavements as those of stone or wood, but that it is highly advisable.

It does not necessarily follow that the work will be done more cheaply than by contract, but it is of great value that small urgent repairs can be made promptly, and with a city plant this can be done.

Assuming that weather conditions will permit asphalt to be laid from the first of May to the first of December of each year, and that there will be twenty days per month suitable for work, there will be 140 working days each season, and a plant having an output of 1000 square yards per day would lay 140,000 yards per year. This would be as much as would be often required in a city of the size mentioned above. It is perfectly practicable, however, to construct one of greater capacity, and it is a matter of record that one Brooklyn plant laid 250,000 square yards of pavement in 1897. In 1912, there were two or three plants in Brooklyn that could produce about 400 square yards of wearing surface per hour.

Location.

This is not decided simply by the streets to be paved. All material used must first be taken to the plant, and as sand forms about 85 per cent of the entire wearing surface, the question of its supply becomes an important factor in determining the location. If sand must be brought from outside, a plant near the railroad or water-front is almost a necessity.

The price of real estate must often be taken into consideration, as what would otherwise be an ideal location might be prohibitive on account of the fixed charges if the cost of the necessary land should be too great.

There is also a certain amount of dust in and around every asphalt plant, and if located in the vicinity of expensive machinery, enough damage may be done to cause a nuisance.

There has been one case of the removal of a plant from a de-

sirable locality simply on account of the destruction to machinery in adjoining buildings by the dust being carried into open windows.

Territory within 2½ miles from the plant can be economically supplied with material. Working ten hours per day, an ordinary team will haul four loads for that distance; but if the haul be much increased, the loads would be reduced to three and the cost of hauling correspondingly increased.

Assuming the wages of a team to be $5 per day and that each load will lay 33 square yards of surface, at four loads per day the cost of hauling will be 3.8 cents per yard for surface and 1.9 cents for binder, or 5.7 cents complete. With three loads per day per team the cost would be 7.6 cents per yard. Where but a small amount of work is projected outside of the 2½-mile limit, the extra expense would not be much, but in establishing more than one plant in the same city it should be seriously considered.

In deciding whether it is economical to have one plant or two the increased haul caused by using one plant only will often be more than offset by the extra cost of operation for two. One large plant properly designed can be operated much more cheaply than two and careful study must be given to the matter before coming to a decision.

The motor truck, too, carrying larger loads more swiftly than can be done by horses, in the next few years must undoubtedly be considered. Some plants in Brooklyn have delivered material to streets distant from their plants in trolley cars.

It is possible, however, in making a final decision upon a location, that the governing principles will be cost of real estate and the facility for receiving the crude material.

The actual work to be performed by the plant is heating the sand and stone for binder, making the asphaltic cement, and sometimes the stone-dust, and mixing these different ingredients in their proper proportions.

Heating the Sand.

This is an important function. To lay 1000 square yards of pavement will require approximately 60 cubic yards of sand and

30 cubic yards of stone for binder. The plant should have a capacity somewhat in excess of that amount, so that a stoppage of a few hours would not interfere with the supply for the mixer. As sand retains its heat when in bulk for a long time, no loss ensues from the storage of quite an amount.

Sand comes to the plant as a rule damp and often wet. All moisture must be evaporated and the material brought to a temperature of 400°. The sand should be heated as uniformly as possible, for if any portion be too hot, it is liable to burn and injure the asphalt even when the average temperature would be satisfactory. Just what temperature asphalt will stand without injury is not positively known, but there is no necessity of heating it much above 400° F.

The sand is generally heated in hollow steel cylinders or drums set at a slight vertical angle. Upon the inside of the cylinder angle-irons are bolted at intervals. The cylinder is set in a solid frame and surrounded by an iron jacket. The heat is applied to the space inside the jacket and the cylinder revolved. The sand is carried on the angle-bars up the side of the cylinder for a certain distance, when it falls to the bottom, is again carried up, the operation being continued as long as the sand remains in the drum. The drum being set at an angle, the sand falls vertically and advances towards the lower end a distance equal to the sine of the vertical angle. The time sand is retained in the drum is regulated by the rate of its revolutions. In addition to the above the capacity of the sand drum will be governed by its diameter and length.

Some heaters are constructed on a somewhat different plan, the heat-space being in the centre of the drum, and the sand falling directly upon the heated cylinder. The other details are practically as given above. An attachment is made by which all dust and steam are carried off.

As the heated sand is delivered at the end of the drum, it is carried by elevators to the storage-bin on the mixing-platform.

Asphaltic Cement.

To lay 1000 square yards of pavement will require approximately 25,000 pounds of asphaltic cement for the top and 6000

pounds for the binder, when made from Trinidad asphalt.* The refined asphalt is melted in kettles and the petroleum residuum or other flux is then added. As a different amount of flux is used for the binder cement, separate sets of kettles will be necessary for economical operation. Three kettles should be provided for the surface mixture and two for the binder. As it requires about eight hours to thoroughly mix the oil and asphalt, as soon as one kettle is emptied it should be immediately refilled so that there will always be some cement ready for use.

The mixing, or agitating as it is generally called, is done mechanically and also by means of air.

The mechanical method consists simply of an arrangement by which what is practically a paddle-wheel is revolved in the kettle, keeping the material in constant motion.

With the air process a series of perforated pipes are laid in and around the inside of the kettles. By means of a pump air is forced into these pipes and through the perforations to the surface, thoroughly mixing the oil and asphalt. It is extremely important that these two ingredients become thoroughly incorporated with each other, so that the flux shall act upon all the asphalt, converting it into a homogeneous compound. After the cement has been thoroughly mixed it should not be allowed to stand for any length of time, lest there may be some separation of the oil and asphalt, but kept constantly in motion until used.

Care should be exercised also when the bottom of the kettle is approached, to see that the cement still contains its proper quantity of bitumen. This is particularly important in asphalts containing a large amount of impurities. A failure to observe this caused a mixture to be sent upon the street that contained but 4 per cent of bitumen. In this particular instance the discrepancy was so great that it was easily detected by the inspector; but had it been somewhat less, or the inspector inattentive, another inexplainable failure of an asphalt pavement would probably have been reported.

* The amount will vary in accordance with the amount of bitumen in the asphalt. Trinidad is used as that contains less bitumen than the other asphalts of commerce, so requires more asphalt.

Stone-dust.

In some localities pulverized limestone cannot easily be obtained, so that a mill for grinding it is necessary. This involves an extra expense in the construction of the plant, and where the stone-dust can be obtained in the market it will generally be cheaper to purchase it. The amount used per square yard of pavement is about 14 pounds.

Portland cement is sometimes substituted for stone dust, especially on heavy traffic streets.

Mixing.

Having the different ingredients already prepared, the next step is the process of mixing itself. The mixer consists of an iron box having a capacity of about 8 cubic feet. Through the bottom of the box run two parallel shafts about eighteen inches apart, to which are attached steel blades some twelve inches long and four inches wide, set at an angle of about 30° to the shaft. The shafts revolve in opposite directions, the blades meshing into each other, thoroughly mixing the material in a very short time. The bottom is made up of two pieces opening by means of a lever from the centre, so that the mixture drops into the wagon or cart waiting below. This part of the machinery is located on a platform high enough to permit a team to drive under to receive the charge.

In the early plants sand was shovelled into an iron bucket containing the right quantity, hung on an overhead trolley, and then pushed by hand to the mixer and dumped. The asphaltic cement is then dipped from the kettle into a smaller bucket, weighed, and then conveyed to the mixer by another trolley, where it is poured upon the sand and the mixing continued until it is entirely completed, the actual time consumed being, on an average, 70 seconds. The binder is mixed in a similar manner in a separate mixer.

In more recent plants sand is stored in a bin directly over the mixer, so that by pulling a slide the proper amount can be dropped into the box without extra labor, and by means of compressed air the asphaltic cement is conveyed to the mixer and the required amounts drawn off by opening and closing a valve. This re-

quires less labor for the operation and has proven very successful.

While the question of plant has been discussed from the standpoint of 1000 yards per day, its capacity can be easily increased by increasing the size of the mixing-box as well as the number and size of the melting-kettles. In the larger plants of recent date the mixing-box has been made large enough to contain 16 cubic feet instead of 8, and as the time required for mixing is practically the same, the capacity of the plant is consequently doubled if the other parts have been increased correspondingly.

Assuming that the actual time of mixing is 70 seconds, but that one charge only will be prepared every 2½ minutes, the plant will turn out in ten hours 240 charges. The charge from the 8-foot box will lay, approximately, 4½ square yards of wearing surface, and from a 16-foot box 9 square yards, giving as the actual capacity of the plant 1080 and 2160 yards, respectively, per day.

Cost.

In estimating the cost of an asphalt plant the necessary buildings and real estate will not be considered, as so much variation can be made in the construction of the one, and the cost of the other varies so greatly in different cities. There is also a great difference in the actual cost of installing an asphalt plant, depending upon its capacity and exact method of construction. If, as has been said before, a large amount of machinery be used, the first cost will be increased, but the expense of operating will be small.

Asphalt Plant.—The first cost of the Brooklyn Municipal Plant, which was completed in 1907, was $24,866.38, and there have been added to it, as betterments, improvements amounting to $3,179, making the total cost up to 1912 $28,045.38. This plant has a capacity of 1500 square yards in an eight-hour day.

On July 15, 1912, The Board of Estimate and Apportionment, of the City of New York, approved plans and specifications for a municipal asphalt plant for the Borough of Manhattan, the estimated cost of which is $75,000. The capacity of this plant will be from 3000 to 4000 square yards of wearing surface per day.

The number of employees necessary to operate a plant will range from nine to twenty, according to size and manner of construction. One modern plant, with a capacity of 1200 yards per day, has been operated by ten people, including foreman, timekeeper, etc.

The Brooklyn plant requires for operation a force consisting of one foreman, three licensed firemen, or stokers, two stationary engineers, and sixteen asphalt workers. Under a State law no man is allowed to work for a city or a contractor on a city contract more than eight hours per day. For that reason the above force is a little larger than it otherwise would be.

The tools and equipment, as well as costs, for the gangs making the repairs on the streets are as follows:

GANG TOOLS AND EQUIPMENT FOR REPAIR GANG.

Number.	Tools and Equipment.	Cost.
1	Bars, crow	$ .70
2	Barricades, large	7.00
4	" small	10.00
2	Barrows	8.00
1	Brooms, corn	.50
2	push	.85
1	Canvas cover, roller	26.65
1	Chain, 25 feet	2.25
6	Cutters, asphalt	4.25
1	Fire wagon	125.00
1	Hose, 1 inch hyd.	4.00
1	Hydrant reducer	.70
4	Lanterns	1.55
2	Pails, asphalt	1.10
1	" cement	.55
6	Picks	2.15
2	Rakes	1.70
1	Roller, asphalt	1600.00
2	Shovels, asphalt	1.20
1	" binder	.65
6	" dirt	3.95
1	" coal	.60
2	Smoothers	5.50
4	Tampers	7.00
1	Thermometer	2.00
1	Wrench, hydrant	.60
	Total	$1,818.45

In addition to the above the Borough of Brooklyn owns the asphalt trucks for hauling the material from the plant to the street, but the horses for doing the work are hired. These trucks cost nearly $500 each.

Portable Plants.

When the asphalt-pavement industry was in its infancy, and for many years thereafter, it was not considered practicable to lay asphalt pavements in cities of small size on account of the expense of the plant. But as this pavement came into general favor and the demand for it became greater, even in the smaller cities, attempts were made to construct portable plants that could be transported easily and cheaply from one city to another. After many trials this was successfully accomplished.

The early portable plant made for transportation on railways was carried on two cars, and at the present time the two-car plant is used by contractors who wish a plant with a capacity of 1500 or 2000 square yards per day.

The one-car railway asphalt paving plant built by Hetherington & Berner of Indianapolis is the natural offspring of the original two-car railway plant which was first invented and brought to successful development about fifteen years ago. While the large two-car railway plant was and is successfully used by contractors who conduct very extensive operations in asphalt paving, it became evident to the manufacturer of those plants that there was a considerable field seldom entered by the larger operators because the individual contracts to be had therein were not of sufficient size to warrant the use of the more costly two-car plant, as it would not have been good business sense to operate a plant having a capacity of more than 2000 yards of pavement per day on contracts which only required a capacity of from 1000 to 1250 yards per day. In all parts of the United States there were towns in which paving contracts could be had provided the contractors could afford to take them at a reasonable price. It was in order that asphalt pavements could be introduced into smaller towns and cities with greater facility that there was

introduced five years ago the Hetherington One-car Railway Plant.

There are many new and unique features connected with the design of this plant which will at once be understood and appreciated by those who are familiar with railway plants as they have been constructed hitherto. One of the principal objects which the designer of this plant has striven to attain was that the plant should be entirely complete in itself and require no extraneous aids or appliances before it could be made ready for operation. Another object was to attain such construction and assemblage of parts that it would not be necessary to dismantle or take apart any of the constructive elements in preparing the outfit for a journey upon the railway. This object being accomplished, it follows naturally that when the plant has arrived at the field of operation, there will be no parts to re-assemble or put together before work may be begun. In this new one-car plant it would be possible to begin sending paving material to the street within two hours from the time the plant has been placed to position, were it not for the fact that about six hours would be consumed in melting the asphalt. How this may be done will be readily understood from the following description:

The machinery and other parts of this plant are permanently established upon a railway car made entirely of steel and designed and built especially for the purpose. At the right-hand end of the car are the two melting kettles, similar in design and construction to those used in the construction of the regular two-car Hetherington plant. At the opposite end of the car is established the engine and boiler, the same having been also designed especially for the purposes of this plant. Adjacent to the power outfit and towards the center of the car is established the sand drier, which is of the single drum-type and of the latest improved kind. Over the sand drum and extending towards the right until it connects with the steel plate housing of the melting kettles is a platform constructed of steel. This platform is the operating floor, and by reason of the design permits of even much more space for the workmen than is obtained in the case of the two-car plant.

Intermediate between the end of the sand drier and the end

of the melting kettles installation is the mixing machine, permanently fixed to the floor of the platform. Adjacent to this mixer and running upon a laterally extending trolley rail, is the usual asphalt bucket to which the melted asphalt is conveyed through a steam-jacketed pipe line by means of compressed air.

At the right-hand end of the sand-drier is a light and compact chain-and-bucket elevator for the purpose of feeding sand from the ground to the receiving end of the drier. When so ordered a second and similar elevator is provided at the opposite side of the car; thus providing one elevator for sand and one for broken stone; by this arrangement the sand pile may be at one side of the car and the broken stone at the other side.

Hitherto it had been necessary, in handling all railway plants, to assemble, put together and erect the overhead hot-sand storage bin, the hot-sand elevator, and many other parts before the plant could be made ready for work. When the plant is arranged for the road the hot-sand bin and the hot-sand elevator, which carries the sand from the drier to the sand bin, are shown erect or vertical. When ready for shipment those parts are shown as lying horizontally, the sand bin upon the top of the platform, and the hot-sand elevator lying alongside of the drier on the deck of the car. This alternation of position may be accomplished in a few minutes, one leg of the elevator being hinged to the car floor and two legs of the sand bin being hinged to the deck of the platform. It is only necessary to detach the fastenings of the free legs and then lower each separately until they assume the horizontal position. The invention and adoption of a new style of rotary sand screen makes this folding arrangement possible, and it is not necessary to remove or in any manner interfere with the sand screen; the screen, elevator, chain and all other attached parts remaining in position in their respective housings. The sand bin is provided with a patent deflecting device for returning the sand to the sand pile instead of putting it into the bin.

In these plants, as first built, the sand bin with its internal screen and other mechanism was lowered from its operative position to its shipping position by means of a rope and block tackle attached to a temporary mast which was furnished with

the plant, and which was stepped into sockets provided therefor adjacent to the side of the bin. In the later plants the rope tackle has been superseded by a small worm-geared winch which is permanently fixed to the floor of the car, under the mixer. By means of this winch only one man is required to raise or lower the bin and the hot-sand elevator. The sand bin and the elevator may be erected into position by only two men, and within fifteen minutes' time they may be ready to run.

In order to facilitate the loading of the mixed material into wagons which are to haul it to the street, two different devices may be used. In one, a steam-jacketed conduit or trough is suspended laterally across the car, beneath the mixer platform. This trough is provided with an internal conveyor, which receives the material from the mixer and carries it out to and beyond the side of the car about three feet. This conveyor is arranged so that it operates in slide guides, and may be pushed back under the mixer platform when not in use. About the tops of the melting kettles are projecting platforms.

At the sides and end of the car, near the boiler, are similar projecting platforms; these are hinged to the car body in such manner that when closed they will meet the roof extension panels, also hinged, and thus make a house, covering the boiler and engine, that may be closed and locked, thus effectually protecting the machinery from weather and thieves.

Warren Brothers Company of Boston construct paving and repair plants of four distinct types:

1. Stationary plant.
2. Semi-portable plant.
3. Railroad plant.
4. Portable plant.

1. *Stationary Plant.*—The stationary plant is intended for a permanent location, and as it is not necessary to make allowance for taking apart and moving the buildings and machinery, it is possible to allow more room for working and a more economical arrangement of the machinery than in the other types of plants. The stationary plant is generally best suited to municipalities having a large area of work, as a permanent location allows for proper facilities for storing and handling the raw material,

and permits the use of bins and mechanical handling apparatus that would not be economical to use with a plant which would be moved from place to place. The stationary plants are thoroughly fireproof, being constructed of steel and concrete, and are substantially built to meet the severe service which the work entails. These plants can be built to have a capacity of from 500 square yards per day up. They can be equipped with either steam or fire melting tanks with mechanical or air agitation; to be either steam or electrically driven; containing one or two mixers; with a combination binder and topping bin or separate bins, as the requirements as to capacity and character of equipment may demand.

2. *Semi-portable Plant.*—The semi-portable plant is intended for temporary location and is generally set up convenient to the material supply. The semi-portable plant is cheaper as to first cost than either the stationary or railroad plant and can be built to any capacity. The plant is simple in design, all steel construction, and all running parts are readily accessible for inspection and repair. The plant is designed to facilitate erection and dismantling, as well as for efficiency of labor cost, operation and maintenance. This plant may be driven by either steam engine or electric motor.

3. *Railroad Plant.*—This plant is constructed on a 55-foot flat steel car built in accordance with M.C.B. standards. The dryer is fitted for burning either oil or coal as fuel. The hot-sand storage bin is much larger than that found on the average railroad plant, and this aids materially in continuous running. The mixing platform is off to one side of the car so that teams may be driven beneath the mixer, or backed under, as desired, The driving arrangement is very simple and substantial, all of the wearing parts—as on the other types of plants—being readily accessible for inspection and repair. The provisions for handling the raw material are such as not to interfere in any way with the continuous operation of the plant, there being chain-belt elevators for handling the sand and stone and a power winch and air-compressing outfit for handling the asphalt from the ground to the asphalt bucket. The boiler capacity is ample to meet the most severe requirements which may be put upon it,

and at the same time furnish steam for melting the asphalt or flux in tank cars.

At a slight additional expense all of the above types of plants may be equipped with special patented attachments, adapting them for laying bitulithic pavement or Warrenite roads. With these attachments they are thus adapted for both classes of construction, bitulithic or Warrenite respectively, and asphalt.

4. *Portable Plant.*—This plant may be operated either in the sand bank or alongside of the railroad where the materials are received, for the entire work, or it may be operated on the street and moved along the work as it progresses. It may be moved from one contract to another by attaching to a steam roller or may be drawn by four horses. It is particularly well adapted to intermittent or small output, such as for repair work, the cost of labor and fuel being proportional to the output. This plant will mix binder as well as topping without any change in the machine. Old asphalt pavement may be reheated and remixed with additional asphalt cement without danger of destroying the asphalt in the old mixture. The asphalt cement is melted in a portable kettle which stands alongside of the plant, and is spanned by the overhead trackway so that the asphalt may be readily dipped into the bucket. The power equipment forms an integral part of the plant itself, and whenever the plant is moved it is not necessary to line up with a traction engine. The engine and boiler have double the capacity necessary for driving the plant, so extra power is always available for other purposes if desired. The plânt is mounted on heavy steel wheels fitted to large cast steel axles and the front axle may be cut under the frames to turn the plant in a short radius. All wearing parts are made very heavy and substantial and the cost of maintenance has been reduced to a ninimum. This plant has a capacity of from 80 to 100 square yards per hour, varying according to the amount of moisture in the sand.

Table No. 65.

ANALYSES OF ASPHALTS FROM DIFFERENT SOURCES.

	Water.	Bitumen		Other Organic Matter.	Mineral Matter.	Total.
		Petrolene.	Asphaltene.			
Trinidad asphalt, crude....	2.03	32.45	22.11	8.12	35.29	100.00
Cuban asphalt..............	0.39	25.46	54.41	2.47	17.03	99.76
Dead Sea asphalt...........	......	35.09	63.18	1.73	......	100.00
Val de Travers asphalt.....	....	8.52	3.92	25.79	61.76	99.99
Seyssel asphalt	....	7.49	4.32	......	88.20	100.01
Texas, Uvalde Co., asphalt..	....	8.79	8.27	....	87.95	100.01
Kentucky asphalt..........	....	3.35	2.42	. . .	94.23	100.00
California Sand-rock asphalt	0.33	11.32	3.81	1.12	83.41	99.99
*Asphalt pavement, Buffalo, N. Y..................	....	4.39	2.83	4.10	88.65	99.97

* Same composition as the Delaware Avenue pavement.

Table No. 66.

ANALYSES OF DIFFERENT ASPHALTS TAKEN FROM A REPORT MADE TO THE MAYOR OF NEW YORK BY THE COMMISSIONERS OF ACCOUNTS, MAY 1890.

Name.	Bitumen Present. Per cent.	Water. Per cent.	Mineral Matter, etc. Per cent.
Barbadoes manjack.................... Mexican asphalt	Nearly 100 pure	Trace	Trace
Utah gum gilsonite........................	99.286	"	0.714
Bermudez asphalt, refined..................	97.779	"	2.221
Standard asphalt, California...........	91.680	6.51	1.810
Alcatraz, crude, dry.......................	68.060	....	31.940
Refined Trinidad pitch............	56.973	.. ..	43.027
Trinidad pitch, crude....................	39.249	27.000	33.751
AMERICAN ROCK ASPHALTS.			
Utah rock asphalt, lime	43.800	....	56.200
Texas, Uvalde Co., rock shells............	12.5	Trace	87.5
Texas, Montague Co., rock sand...	9.189	"	90.861
Indian Territory, rock sand................	11.442	"	88.558
Indian Territory, rock lime................	8 to 11	"	89 to 92
EUROPEAN ROCK ASPHALTS.			
Limmer rock chalk........................	14.30	"	85.70
Lobsam rock chalk........................	12.32	"	87.68
Seyssel rock chalk........................	11.802	"	88.198
Val de Travers rock chalk.....	10.15	"	89.85
Ragusa rock chalk........................	8.92	"	91.08

Refined Trinidad asphalt contains about 10 per cent of organic matter not bitumen.
Trinidad crude asphalt contains about 7½ per cent of organic matter not bitumen.
In other varieties a trace only of such organic matter is found.
Oil asphalt can be considered as containing 99.5 per cent of bitumen.

CHAPTER XVII.

THE PROTECTION OF PAVEMENTS.

The greatest difficulty in keeping pavements in repair in the United States is undoubtedly that caused by the openings made in them for the construction and repairs to subsurface work. It often seems as if corporations or individuals were simply waiting to have a new pavement put down in order to dig it up and destroy it. No one thing gives municipal the engineer so much trouble and dissatisfaction as this, and there is no one thing for which he is more criticised, despite the fact that he cannot prevent it. With a large amount of subsurface work in the streets of our large American cities it must be accepted as a fact that a certain number of openings must be made; the real task of the engineer is to reduce them to a minimum.

So many varied interests control the different properties in the streets that their collection in a single subway is impracticable, and if it could be done it is uncertain to just what extent the number of openings would be reduced.

In the City of Boston during the year ending January 31, 1910, 13,597 permits were issued for the opening of streets for different purposes, and the length of the openings was 151 miles; this in a total street mileage of 487.

In the Borough of Manhattan, New York City, in 1911 there were 25,179 openings made of various sizes, in a total street mileage of 440. In the Borough of Brooklyn, New York City, during the year 1911, the Bureau of Highways relaid pavements over trenches made by plumbers and the different corporations of an amount equivalent to seven miles of streets 30 feet wide.

The above quantities are startling, and at the same time it is undoubtedly true that a proportionate number of openings are made in the streets of the other cities of the country.

The damage done to the pavements by these openings is not simply the cost of relaying the pavements actually taken up, but also the adjacent pavement is subjected to an undue and abnormal wear. Most cities realize the importance of reducing these openings and are taking steps, not only to reduce the number of openings, but also to reduce the inconvenience to the public while the openings exist.

In order to carry out the latter idea the following rules, to be observed by parties making openings in pavements, have been put into force by the President of the Borough of Manhattan:

"The applicant agrees to comply with all the rules and regulations printed upon the back of or referred to in this application, as well as all other laws and ordinances relating to such work; and the acceptance of the permit shall be deemed an agreement to abide by all of its terms and conditions as herein set forth.

Deposit.—A public service corporation may make a cash deposit or give a bond and make an additional smaller cash deposit in advance—an amount which in the opinion of the Commissioner of Public Works shall at all times be sufficient to cover all expenses to the city as above set forth; provided, however, that the Commissioner of Public Works may discontinue such arrangement at any time and require a specified charge for each opening.

The City of New York shall not be liable for any interest on deposits made as provided in any part of this permit.

Yardage Rate.—The charge shall be based upon an arbitrary rate per square yard. Should a settlement occur in the restored area or other defect develop therein within six months from the date of restoration, which in the opinion of the Chief Engineer in charge, after proper notification of and conference with the permittee, was due to improper workmanship below the pavement itself, the Borough President, on behalf of the City of New York, will again replace the restored pavement, the cost of such restoration to be charged against the permittee.

Time Limit.—In case the work has not been completed before the day of expiration as shown in the permit, the Borough President may, if he deems necessary, take steps to back fill the trench and replace a permanent pavement over the opening for which the permit has been issued; and if an extension of time beyond

said date is needed for the completion of the work, a new application must be filed.

Subsurface Plans.—Upon the completion of the work the permittee shall furnish to the Commissioner of Public Works plans of such character as he may direct, showing accurately and distinctly the location, size and type of construction and complete dimensions of the structure installed. The depth below the street surface of the new structures must be shown; also their location with reference to the nearest curb line and curb intersection. No refunds will be allowed by the Commissioner until such plans have been submitted.

Excavation.—The work shall be so conducted that the water mains or service connections, the sewers or house connections shall not be interfered with. All rock within 5 feet of a water main shall be removed without blasting. No excavation shall be made within 4 feet of the trunk of any tree without the approval of the Park Commissioner.

Back Filling.—The applicant further agrees to replace, as far as possible, all material excavated, making use of flushing, tamping or other means to accomplish this end, and supplying any deficiency; and that in case the inspector shall deem the material unsatisfactory for backfill, and this decision shall be concurred in by the Chief Engineer of the Bureau of Highways or duly authorized assistant, then the applicant shall backfill the trench with sand, hard coal cinders or other proper material, removing all excess of original material from the premises. If tamping alone is employed, the material shall be replaced in layers not to exceed 3 inches in thickness, each layer tamped so as to be as thin as possible.

Planking.—Upon completion of the backfill, the applicant further agrees to lay in the cut in the pavement temporary planks of suitable thickness and quality, all securely fastened together, or if permitted in writing, other material satisfactory to the Commissioner of Public Works—such as hard-coal cinders wetted and heavily tamped, all properly supported so as to bring its top flush with the pavement surface.

Final Restoration.—At the time of making the repair the concrete base shall be removed for a space at least 6 inches larger

on all sides than the dimensions of the trench excavated, all old concrete work to be properly grouted, and fresh concrete laid so as to secure a good bond with the old concrete and a firm foundation on the untouched sides of the trench. The portion of the pavement which rests upon the new foundation shall be replaced by the city over an area 6 inches larger on all sides than the area of the new concrete above described; all of such work being done in order to secure a proper bond and to prevent improper settlement.

Notice to Bureau of Highways.—The Bureau of Highways shall be notified four working hours before the time when the opening in the pavement is to be made, so that an inspector of the Bureau may be present, and until such proper notification has been made no opening in the pavement shall be undertaken unless special permission, in writing, is given by the Borough President to make such without the presence of an inspector. The Bureau of Highways shall also be notified four hours before completion of backfill so that proper orders may be issued for permanent pavement replacement. If after proper notice has been given the Bureau of Highways and acknowledged by it, an inspector has not visited the work the permittee may proceed therewith."

The further problem, then, is to reduce the number of openings to a minimum and also to see that they are repaved as promptly as possible. It should be understood that the streets are for the use of the public, and when it is necessary for any corporation to obstruct them it must put itself to considerable expense and inconvenience so as to protect the public.

Rules can be made that pavements shall not be opened for a certain length of time after they have been laid, but when leaks occur in sewer, gas or water mains they must be repaired or the pavements will be more damaged than if left alone.

The question then is what methods to take to reduce the number of these openings.

In Cincinnati an ordinance prohibits the tearing up of new streets within three years after the time of their construction, macadam streets being excepted. The ordinance provides for

ninety days' notice of contemplated street construction to property owners and to public service commissions and also to the director of public service, who is required to compel the laying of sewer and water pipes before streets are constructed. Failure of the property owners to get notice of the proposed improvements or failure to put in the underground accessories in advance will not be accepted as an excuse for permitting them to tear up the streets after they have been built. The ordinance applies to all streets to be improved after its passage which are not already under construction.

The measure also provides that if property owners do not have service connections laid from the sewer and water mains to the curb the city will have this done and collect the cost from the property owners in the same way that sidewalk assessments are collected.

In New York City the Board of Estimate and Apportionment will not authorize the paving of a street unless the water, sewer and gas mains have been laid. In the Borough of Brooklyn the Sewer Bureau includes in its contract for the sewer proper, the laying of house connections within the curb lines in front of each lot. In Rochester, N. Y., the contracts for pavements require that sewer connections shall also be laid within the curb lines in front of each lot, as well as water and gas service pipes. The spur connections are made by the contractor. The gas service pipes are laid by the gas company which owns the main. The water service pipes shall also be laid by the contractor, in accordance with the rules and regulations of the Commissioner of Public Works. All necessary surface sewers or drains are also provided for in the paving contract.

Probably, however, the most elaborate and effective steps in the direction of pavement protection have been taken by the City of Philadelphia.

In 1884 there was organized in that city what is known as the Board of Highway Supervisors under an ordinance passed in March of that year "for the purpose of preventing frequent and unnecessary openings in streets and street pavements; to promote system and economy in repaving over breaks made for underground work."

The board is composed of the Director of Public Works, the Chief of the Bureau of Highways, the Chief Engineer of Surveys, the Chief of the Bureau of Water, the Chief of the Electrical Bureau and the Chief of the Bureau of City Property. The board is vested with full power, not only to grant original locations to companies authorized by law to lay pipes and conduits, but also to direct their removal and relocation whenever the public good may demand it.

For the purpose of enabling the Board to act intelligently on applications, a recording and drafting department is maintained where all underground structures are plotted and their sizes, depths, distance from the curb or building lines shown upon plans of uniform size drawn to a scale of 20 feet to the inch. Each structure is colored with a conventional tint so that may be followed on the plans. The ever increasing demand for space under the street surface makes it necessary that the available cross-section be utilized to the best possible advantage. This, in a measure, is accomplished by grouping the structures as closely together as possible. They are required to be laid in locations parallel with the street line and any continuation of existing work must be laid in the line of the original substructure. These extensions are borne in mind when locations are given for new structures.

The accuracy of the records in the drafting room of the Board of Highway Supervisors is so to be depended upon that when sewers, water pipes or other underground structures are to be laid in the streets their location can be determined with sufficient exactness to admit of the perfection of the plans for the work without the necessity of making advance excavation.

All applicants for permits to locate pipes, conduits and other subsurfaces structure are required to obtain plans from the department records, showing by cross-sections all existing structures in the street. These plans are used by the Board in considering the applications and in fixing the locations. By this means an intelligent supervision is constantly kept of every class of construction placed under the surface of the streets, and the city, by reserving space which may be required in the future, obtains a maximum degree of utilization of the width of the street available for uses of this kind.

A charge per linear foot is made by the city to parties obtaining plans and information and the cash receipts are considerably more than sufficient to maintain the force in the drafting room and the field inspectors, who are sent to see that the locations granted are followed and to make systematical measurements and daily reports covering structures of every character met with in the excavation. From these returns the plans are constantly being checked, and, where necessary, corrected. In addition, upon the completion of the laying of any underground work, either the bureau of the city or the private corporation having charge of same is required to return to the Board of Highway Supervisors a complete plan giving the exact location occupied and the sizes and positions of every kind of construction met with during the progress of the work. This gives a complete and valuable record for future reference.

The charge for the information is as follows:

For furnishing plan indicating all underground structures 5 cents per linear foot for any continuous length in the one street up to 2500 feet (5 blocks) and 3 cents for each additional foot. Where locations are given on unpaved and macadamized highways a straight charge of 1 cent per linear foot is made on account of the fact that these highways are generally located in the suburban sections and contain but few underground structures. Upon the completion of the work the bureau sends an official to make a survey and record the exact location in which the structure is placed, and for this a charge of 2 cents per linear foot is made (on every class of street), but in no case is this charge less than $5.00. That is, if a telephone company applies to the Board of Highway Supervisors for a plan showing the underground structures in a street, covering a length of 1000 feet, they would be charged at the rate of 5 cents per linear foot, or $50.00 for the plan, and upon the completion of the work the bureau makes a complete survey of the location of the structure and all manholes, spurs, etc., for which the company is charged an additional 2 cents per linear foot, or $20.00, so that the total cost to the company for the stretch of 1000 feet amounts to $70.00; on the other hand, for a length of 5000 feet, the charge for the plan would be at the rate of 5 cents per linear foot for the first 2500

feet, or $125.00, and at the rate of 3 cents per linear foot for the remaining 2500 feet, or $75.00, making the total plan charge $200.00, while the charge for the survey would be at the rate of 2 cents per linear foot for the entire distance, or $100.00, so that the total cost to the company for the stretch of 5000 feet would amount to $300.00.

The board has been working for so long a time and in such detail that it has practically all of the subsurface construction in Philadelphia accurately plotted, so that it can readily assign to any applicant the best location for any new work. In this way the space in the streets is most economically used, as by this system nothing is done in a haphazard way, but all structures located according to a definite plan.

The fees referred to at the present time create a fund sufficient to pay all the expenses of the board, so that it is self-sustaining.

A copy of the rules of this board, adopted November 8, 1906, governing the laying of electrical conduits is herewith given. Philadelphia can certainly be congratulated in being the pioneer in this work as well as for the results that have been accomplished.

Rules and Regulations of the Board of Highway Supervisors,

governing applications for the laying of electrical conduits, tubes and manholes, adopted November 8, 1906:

SECTION 1.—Companies, corporations, firms or individuals applying under the general ordinance of August 5, 1886, "Regulating the laying and construction of underground wires, electrical conductors, conduits, cables and tubes in the City of Philadelphia," shall file with the Board of Highway Supervisors:

1st. A.—An application, in writing, giving full name of company, corporation, firm or individual, together with amount of capital, business address—the names of officers and directors with address.

B.—The purposes for which they wish to use the streets.

C.—Character of conduits, manholes, tubes, etc.

2d. At least two copies on Linaura of plans, showing all existing underground structures and complete details of proposed construction.

3d. Such other information as may be required to enable the Board to reach a clear understanding of the whole subject.

SECTION 2.—Before any street surface shall be broken, or a permit be issued (except as herinafter provided), the following rules and regulations, and such additional rules and regulations as the Board of Highway Supervisors may from time to time adopt, shall be binding on the applicant or applicants.

1st. "A."—The execution of bond, etc., to comply with general ordinance, "B." compliance with the ordinance granting special privileges, "C." compliance with the rules of the Board of Highway Supervisors.

2d. A certificate from the City Solicitor that the necessary bond and agreement has been filed.

3d. A certificate from the City Treasurer that the requisite payments have been made.

4th. An agreement from the Contractor who is under liability for the maintenance of any street desired to be broken, stating that the guarantee will in no way be affected by the breaking of the same.

SECTION 3.—After the approval of the Board of Highway Supervisors and the issuance of the permit, the terms and conditions of the application and the accompanying plans shall not thereafter be altered or departed from withoutithe consent of the Board previously obtained; except that in cases of emergency, the Chief of the Electrical Bureau may authorize modifications when necessary, reporting his action to the Board at its next meeting.

2d. Where a conduit crosses a bridge, a plan shall be submitted to the Chief of the Bureau of Highways, and no conduit laid thereon until such plan is approved.

3d. On undedicated streets the consent of the owner or owners shall be first obtained, and affidavits to that effect filed with the Board of Highway Supervisors.

SECTION 4.—Before any street surface shall be broken, under a permit as above, notice must be given, in writing, by the receiver of the permit, to the Chief of the Bureau of Highways and the Chief of the Electrical Bureau, of the time, place and extent of the proposed breaking; and where a conduit is located on the

sidewalk, the District Surveyor shall be notified of the location and the date of commencing the work.

SECTION 5.—1st. No portion of any new structure, when in place in the street, except such as is designed to form a part of the street pavement, shall be less than two (2) feet below the surface of said pavement, except with the written approval of the Chief of the Bureau of Highways; and the tops of iron structures forming parts of the street pavement shall have a roughened surface with projections rising not less than one-half (½) inch, and spaced not more than two and one-half (2½) inches apart, as approved by the Board of Highway Supervisors. All manhole covers upon streets paved with asphalt, vitrified brick or wooden blocks shall be filled with asphaltum or other material to the satisfaction of the Department of Public Works.

2d. New work and new structures shall not interfere with existing pipes, sewers, conduits, or other structures, or their connections, except where absolutely necessary, and then only with the previous consent, in writing, of the Chief of the Bureau having charge of such structures. Any modification of existing structures found to be necessary must be made by or under the direction of the Bureau concerned and at the expense of the party having the permit. All necessary supports and protections to existing structures must be promptly supplied by, or at the expense of, the party having the permit, and to the satisfaction of the Bureau concerned. The said party shall erect and maintain and bear the expense of all necessary guards and danger signals, furnish all necessary watchmen to protect the public and the work during its progress, assuming all liability for accident or damage to persons or property that shall occur in the course of or by reason of said work, and agree to save harmless the City, its officers, agents and servants in all such cases.

3d. When, in the judgment of the Board, it shall be deemed desirable to employ one or more special inspectors to supervise the work, such inspector or inspectors shall be appointed by the Director of the Department having supervision over the same, and a sufficient sum deposited by the party receiving the permit, with the Chief of the Bureau, for the payment of such service.

SECTION 6.—1st. Openings in streets shall be made at such

times and places, and be supported and guarded in such manner as, in the judgment of the Chief of the Bureau of Highways, will least interfere with the rights and convenience of others, and interrupt the traffic of the streets no more than is absolutely necessary.

2d. Material and tools for construction must not be delivered in the street till needed for immediate use, and then must be so placed as to cause the least interruption to traffic. Not more than five hundred (500) feet in length shall be obstructed or occupied at the same time, without special authority of the Board.

SECTION 7.—1st. All openings in streets must be promptly filled with suitable material, free from rubbish and perishable matter, and thoroughly and evenly compacted throughout, by ramming in thin layers while being put in, or by puddling. The pavement of street or footwalks must then be at once restored with the same character of material, equal in composition and color to match old work, in accordance with the standard specifications of the Department of Public Works, Bureau of Highways, for such class of work, and maintained in good condition, satisfactory to the Department of Public Works, during the time of any existing guarantee, or as required by Ordinance of Councils, but in no case for a less period than five (5) years. All permits are issued subject to Ordinances of Councils regulating the paving and repaving of streets.

2d. Surplus and condemned material must be removed, and the street cleaned and entirely restored, without delay.

SECTION 8.—1st. All subsurface structures and all surface structures forming part of the street must at all times be kept in good repair. All work and material used in restoring or repairing the street shall be satisfactory to the Department of Public Works, and when notice calling attention to needed repairs is given, it must receive attention within twenty-four hours.

2d. All work and material used in the construction of electrical conduits and manholes must be satisfactory to the Chief of the Electrical Bureau, and any work or material condemned by him must be at once made satisfactory.

SECTION 9.—Immediately after the completion of the work,

the party to whom the permit is issued shall file complete plans in detail to a scale satisfactory to the Board, showing the work as constructed, with all previously existing structures encountered during the construction of the work.

SECTION 10.—Should work necessary to protect the public in the use of the street be omitted or imperfectly performed by the party holding the permit, then after notice the Chief of the Bureau of Highways may cause the work to be done at the expense of the party receiving the permit. Failure at any time to fully and faithfully comply with these regulations, and such further regulations as the Board may from time to time prescribe, or promptly pay such expense as hereinbefore or hereinafter authorized, shall at once work a forfeiture of permits issued, and debar the party from receiving any further permits until relieved by action of the Board of Highway Supervisors.

SECTION 11.—Permits for electrical house connection for the construction of manholes on lines of underground conduits already constructed, where such construction is of advantage to the City or the betterment of the system, may be issued by the Bureau of Highways after approval by the Chief of the Electrical Bureau, without reference to the Board of Highway Supervisors. House connections shall follow the line of conduit and not cross streets diagonally.

SECTION 12.—If, in the laying of water or gas pipes, sewers, or any other municipal work, it shall become necessary to change the location of any of the conduits, manholes or other structures, they shall be shifted or altered at the cost or expense of the owners, to such places as shall be directed by the Board of Highway Supervisors.

2d. Where the City constructs or reconstructs sewers, or lays or relays water pipes, the Company shall maintain its conduits.

SECTION 13.—No permit will be valid for more than the number of days specified therein, which shall be determined by the Board of Highway Supervisors at the time the permit is authorized; for any subsequent work a new permit must be obtained.

SECTION 14.—Persons in charge of any work on the streets must have in their possession, at all times while so engaged, the permit issued by the Department.

SECTION 15.—All permits shall expire on December 31st of the year in which they are issued.

Probably no other city in the world has a greater maze of substructures in its streets than the City of New York. These substructures consist of sewers; water mains; gas mains; elevated column foundations; conduits, conveying electric current for light and power; telephone conduits; conduits conveying electric power for the operation of the various surface railroads; mail tubes through which mail is distributed by compressed air to the various railroad terminals and the sub-stations of the general post-office; police and fire alarm conduits; conduits conveying the inshore ends of the transatlantic cable lines; steam pipes of the New York Steam Company, conveying steam for heat and power; refrigeration pipes; pipe lines of the oil companies; vaults under the sidewalks; private tunnels, connecting properties on opposite sides of the streets, conveying light, heat and power, etc. Substructures of this character have been accumulating for years in the principal thoroughfares in this city, and unfortunately little is known relative to their location or size. In consequence, it has become a fixed practice, preliminary to the installation of new structures, to resort to pavement mutilation by digging test pits in order to determine a feasible location. These test pits are dug at intervals of about 100 feet, and frequently pavements on several thoroughfares are mutilated in this manner before a satisfactory route is determined. This mode of procedure is at best only a make-shift, as long as the intervening space remains a mystery. When the work is in progress and this space is uncovered it is not unusual to find unlooked-for structures of such importance that to avoid them special construction must be resorted to. This practice delays the work, keeps the thoroughfare obstructed for a greater length of time, results in additional pavement mutilation and increases the cost.

The most important subsurface work ever carried on in this city was the construction of the elaborate system of passenger-carrying subways, which in many instances occupy the entire width of the streets. Provision had to be made for practically

all substructures encountered; in consequence, it was necessary to prepare subsurface record maps in advance of the work. These subsurfaces records were used in connection with the actual designing of the structures and were made a part of the contract drawings, giving the prospective contractor much valuable information as to the type and character of the substructures to be cared for during construction. This, without doubt, resulted in a material saving in the cost of the work.

Fig. 92 is taken from a photograph showing a maze of substructures exposed during the construction of the subway at Fifth Avenue and 42d Street.

Fig. 93 shows pipes and conduits found at 57th Street and Broadway. A close examination of these two last figures will disclose how many makeshift devices had been used when unlooked for obstructions were encountered.

Fig. 94 is a view looking down vertically into a junction box. Note the maze of cables and how they change direction in the box.

The municipal authorities for years have recognized the necessity of a more systematic control of subsurface conditions and during the latter part of the year 1906, a moderate appropriation was obtained by the President of the Borough of Brooklyn to be used in establishing a Division of Substructures to be attached to his office. The work was put in charge of a competent engineer with the following objects in view:

Accumulating all information obtainable as to the size, location and character of structures under the streets and avenues in the Borough, and recording the same on durable maps.

Assigning definite locations for new substructures.

Reducing pavement mutilation to a minimum.

Conserving as far as possible for future utilization subsurface spaces which are rapidly becoming one of the city's most valuable assets, and from which substantial revenues will be derived through future franchise grants.

Furnishing to applicants seeking subsurface space for tunnels, pipe lines, etc., information as to the location and size of existing substructures. Such information is required by the Board of Estimate and Apportionment when applications are filed for franchises.

Fig. 92.

Fig. 93.

Fig. 94.

Furnishing other city departments with information to be used in connection with the location and construction of subways, sewers, water mains, etc.

Brooklyn is one of the largest boroughs in the Greater City

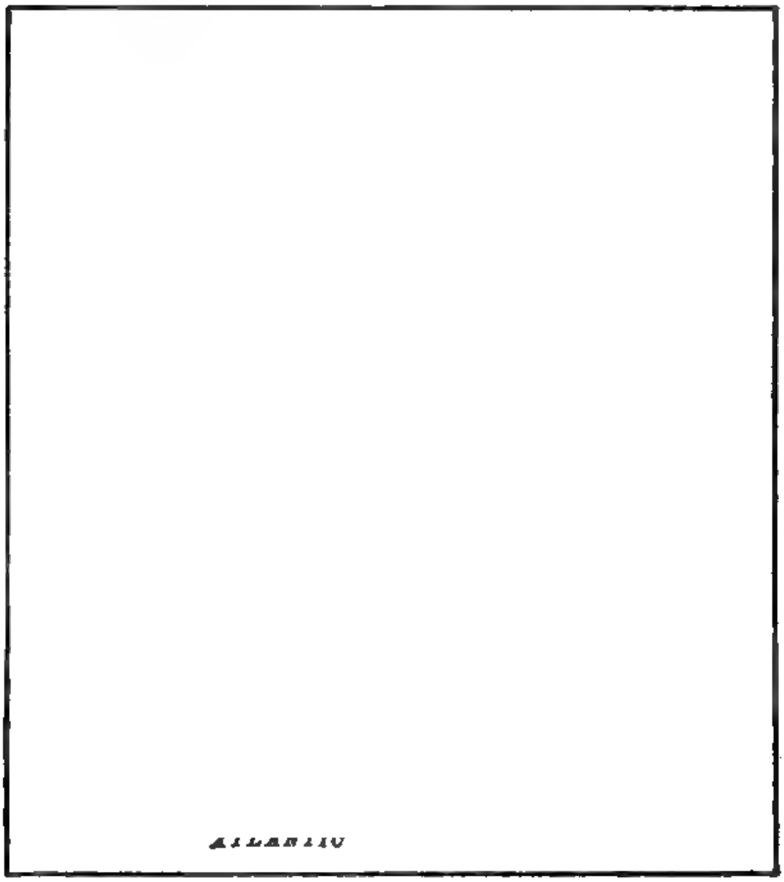
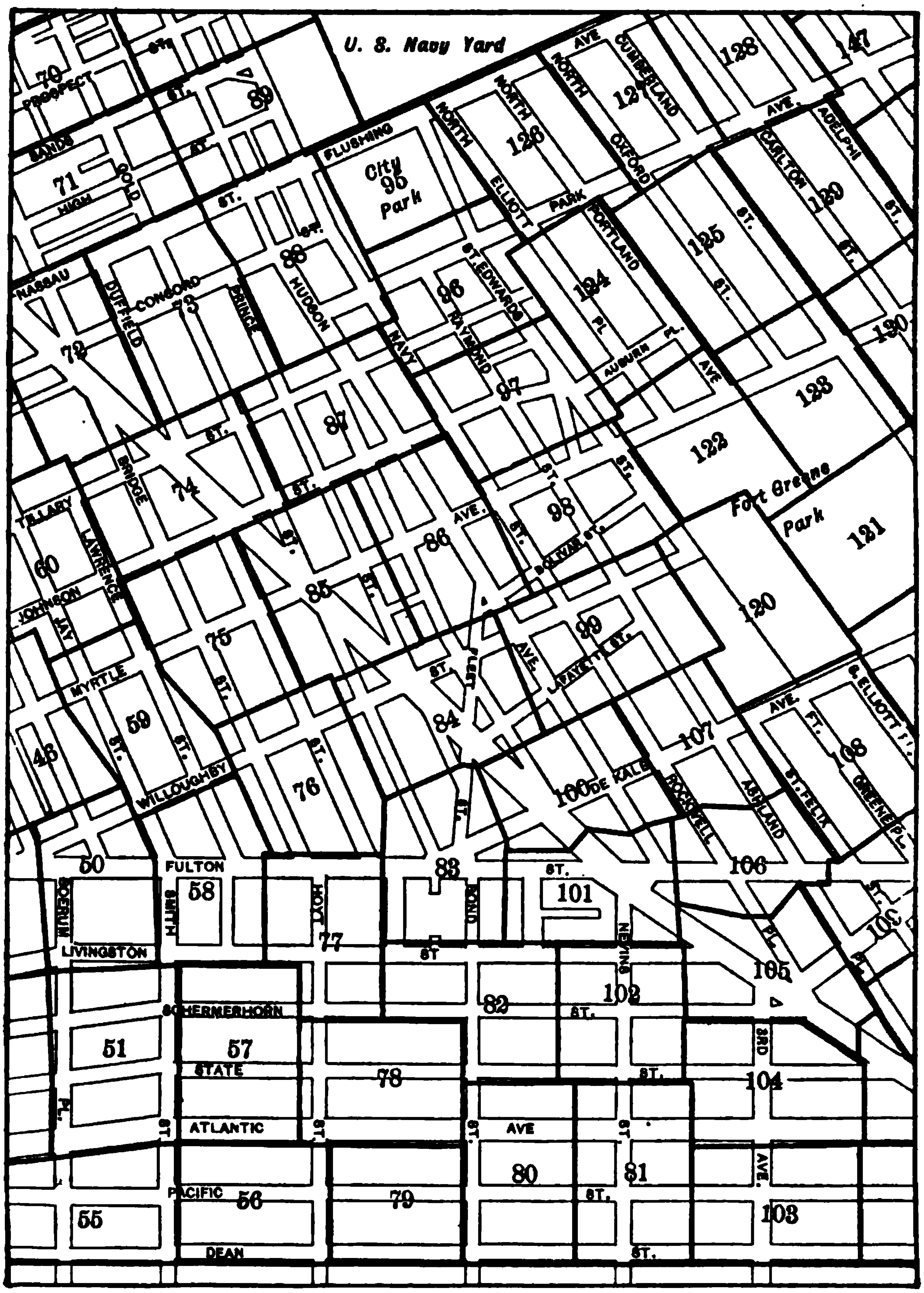


FIG. 95.

of New York, with an area of 77 square miles, a population rapidly approaching the two million mark, a highway system of practically 1200 miles and 900 miles of sewers.

Preliminary to preparing the subsurface record maps it was


U. S. Navy Yard
City 95 Park
Fort Greene Park
PROSPECT
SANDS
HIGH
GOLD
NASSAU
CONCORD
DUFFIELD
PRINCE
HUDSON
FLUSHING
NAVY
RAYMOND
ST. EDWARDS
NORTH ELLIOTT
NORTH PORTLAND
CUMBERLAND
OXFORD
PARK
PORTLAND
AUBURN PL.
CARLTON
ADELPHI
BRIDGE
TILLARY
LAWRENCE
JOHNSON
JAY
MYRTLE
WILLOUGHBY
BOLIVAR ST.
FLEET
LAFAYETTE ST.
DE KALB
ROCKWELL
ASHLAND
ST. FELIX
S. ELLIOTT PL.
GREENE PL.
FULTON
SMITH
HOYT
BOND
NEVINS
BOERUM
LIVINGSTON
SCHERMERHORN
STATE
ATLANTIC
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3RD
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FIG. 96.

decided to adopt a system whereby the maps could be prepared in any section of the Borough without consequent confusion and duplication. The large area to be covered was divided into twenty sections and each section treated separately. The sections are numbered 1 to 20 as shown in Fig. 95.

Record maps are plotted on a durable cloth-mounted paper in sheet form 32 inches wide and 42 inches long, to a scale of 20 feet to the inch. These dimensions provide amply for a city block length of 800 feet and are the maximum size sheet that can be readily handled.

The next step was a systematic arrangement of record maps so as to cover economically a section or part of a section. In other words, the preparation of a record map layout. This was accomplished by using templets of tracing cloth and applying them to a large-scale city map. The city atlas drawn to a scale of 100 feet to the inch was used. Tracing cloth templets cut to a scale of 100 feet to the inch correspond in size to the record maps which are plotted to a scale of 20 feet to the inch. Consequently, the area covered by a templet on the city map is the same as the area covered by a record map on the ground. With care and ingenuity excellent results are obtained and a record map layout is prepared, using the minimum number of maps to cover a given area.

The outline of the streets in the area to be covered by the record maps is inked in on the templets and they are laid aside for future use, which shall be described later.

Part of a section layout is shown in Fig. 96.

With this method it is possible to make subsurface investigations, prepare record maps in any locality, and obtain a systematic record of such operations. The record maps are numbered consecutively in accordance with the section in which they are located, that is, a record map numbered 1–25 would mean that it is a record of subsurface investigations taken in section No. 1, over an area covered by record map No. 25. This system of section and record-map numbering permits of a comprehensive filing system, as all information is filed in accordance with its section number and record map number.

In sections of the Borough where the street system is extremely

irregular and made up of two or three rectangular systems cut through by an important diagonal thoroughfare, a record map layout is determined, covering the important thoroughfare. The problem presented in making this layout is to cover by not more than one record map complicated street intersections, thereby avoiding splitting up these intersections, which would necessitate plotting part on one record map and part on another. With a determination of a systematic layout covering this thoroughfare a layout is next determined for the adjoining rectangular systems, which usually presents but few difficulties.

Upon the completion of a record map layout, surveys and investigations are made on the ground. The surveys are made from established base lines and include the location of curb lines, building lines, car tracks, hydrants, manhole covers, corner basins, gas drips, elevated railway columns, poles, and in fact any object on the surface that will serve as a guide in determining the size and location of the underlying structure. These locations are obtained by right-angle offsets from the base lines. The stationing of the offset points on the base line is determined by the use of an optical square. This small instrument has proven to be a great time-saver. Upon the completion of the survey within the area covered by the record map or maps to be prepared, investigations are made of all manholes. The usual procedure is to investigate sewer manholes and appurtenances first. Using a specially designed sewer rod the depth and size of the sewer is determined from the street surface and the type of construction and condition noted. The corner basins are surveyed in a similar manner. It is often necessary to flush corner basins from the near-by hydrants to determine, particularly at street intersections, into which sewer they empty and obtain an approximate location of the connection. Unfortunately, the records of sewers constructed in the older section of Brooklyn years ago are in some instances missing and in other instances so incomplete as to be of no practical use. The manholes of other structures are taken up in turn, the iron covers removed and full measurements taken, showing the location and size of the conduit line or pipe line entering and leaving the manhole. In the case of the large manholes or junction boxes of the electric companies a special

extension rod is used for taking the various measurements. By use of this rod it is possible to obtain practically all the measurements from one position in the center of the manhole.

These investigations afford a fund of accurate information as to the size, depth below the surface, and location of substructures at frequent intervals in the thoroughfare under investigation. The direction taken by pipes, conduits, etc., between manholes is often disclosed by the outline of a strip of pavement relaid after the installation of a new structure or repairs to an existing structure. Locating these traces of pavement cuts is part of the work of the survey party. All irregularities, such as broken manhole covers, clogged sewers or corner basins, broken hydrants, gas-laden junction boxes, etc., are noted and brought promptly to the attention of the city department or public service corporation responsible. While these surveys are under way a repsentative is sent to the offices of the different public service corporations and city departments for all information obtainable relative to substructures maintained by them in the city thoroughfares. This information includes test-pit records, general location of structures, standards of construction and plans of special work installed over the area under consideration. The record maps are then plotted. The maps are laid out in strict accordance with the outline of the area to be covered as shown on the templates previously referred to. The survey notes are accurately plotted and checked, including all information from the offices of the public service corporations and city department. The plotting of these maps is the most important part of the work, as it involves so much troublesome detail. All surface locations, such as building and curb lines, trolley tracks, manhole covers, etc., are shown in black, while the various substructures are shown in distinctive colors, electric light and power conduits are shown in red, gas pipes in green, water pipes in blue, telephone conduits in brown, etc. In consequence, it is not a difficult matter to trace out a run of any particular pipe or conduit line. Water colors are used for the reason that it is necessary from time to time to make corrections to conform with changes constantly taking place, and erasures can be made with but slight injury to the paper.

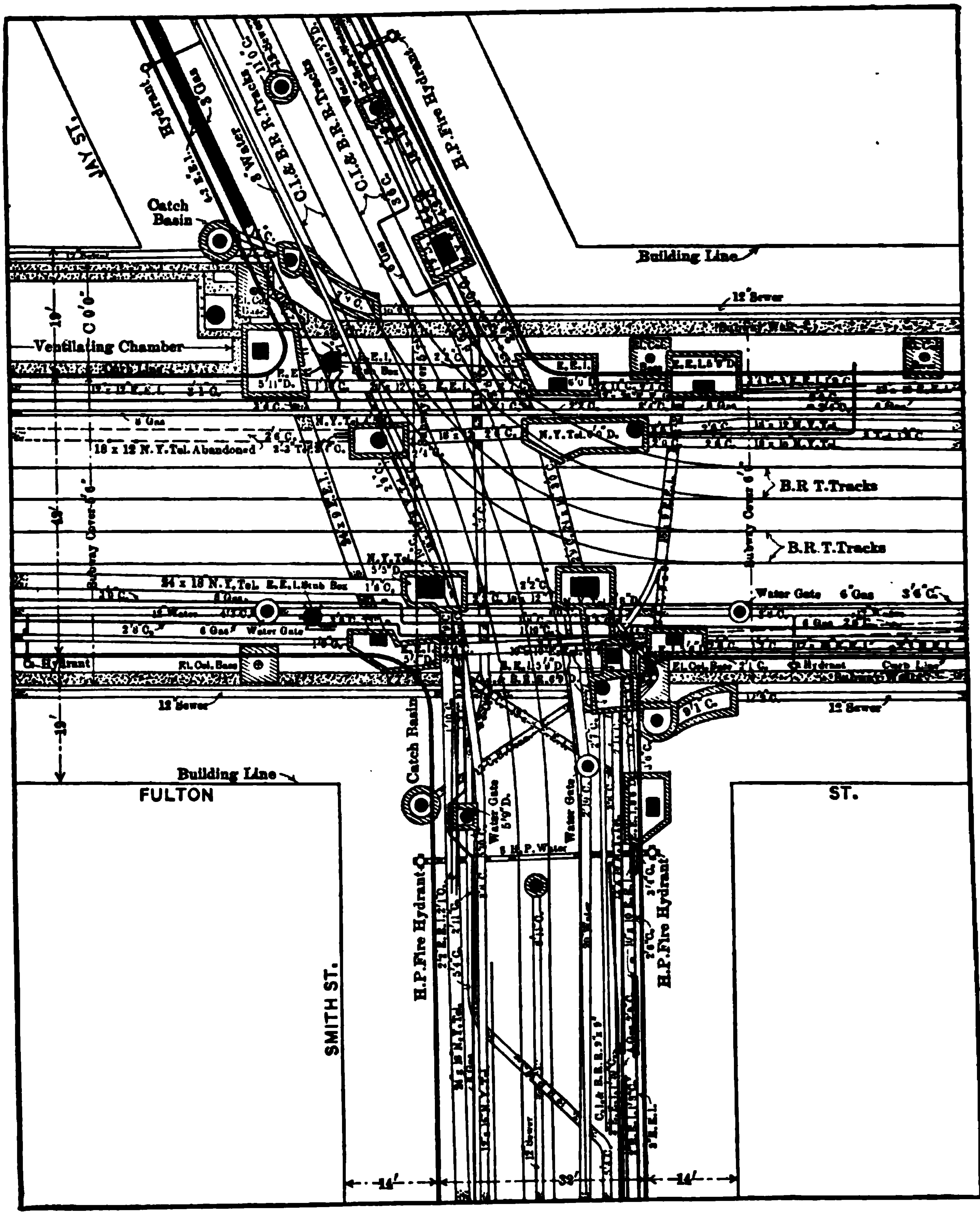
JAY ST.
Hydrant
3" Gas
8" Water
C.I.& B.R. R.Tracks
H.P.Fire Hydrant
Catch Basin
Building Line
12" Sewer
Ventilating Chamber
18 x 12 N.Y.Tel. Abandoned
B.R.T.Tracks
B.R.T.Tracks
Subway Cover
24 x 18 N.Y.Tel. E.E.I.Stub Box
Water Gate
6" Gas
12" Water
12" Sewer
Building Line
FULTON
ST.
Catch Basin
SMITH ST.
H.P.Fire Hydrant
H.P.Fire Hydrant
Water Gate
8 H.P. Water
12" Sewer
14'
14'

FIG. 97.

Fig. 97 is a reproduction of a street intersection as shown on a record map prepared by the Division of Substructures, Brooklyn.

All applications for permits to make new installations and repairs to existing structures are referred to the Division of Substructures for criticism, prior to the issuance of permits. In this way the Engineer in Charge is kept in close touch with such work and pavement mutilation, and interference with existing structures is materially reduced. During the progress of the work measurements are taken on the ground, relative to the location of the new structures, and all structures encountered. This information is filed in accordance with the number of the section and number of the record map, covering the area in which the work is located. If a record map has been prepared, covering the area the information is plotted by a draftsman assigned to the special work of correcting record maps, thereby keeping them up to date.

While definite locations are frequently furnished for new installations, much work has been done in connection with the preparation of subsurface drawings in advance of public work of importance, such as the construction of passenger-carrying subways, trunk sewers and the installation of large water mains. The subsurface information accumulated is used in preparing the construction plans and is also made part of the contract drawings. Probably the most extensive investigations were made in advance of the installation of the large water distribution mains, a part of what is known as the Catskill Water Supply System.

While it is a difficult matter to calculate dollar by dollar the saving involved by this systematic procedure, it is conservatively estimated that the saving is at least equivalent to the entire cost of the Division of Substructures to date.

Excellent progress has been made. Section 1 is practically completed and record maps have been prepared in portions of Sections 2, 3, 4, 5, 17, and 19. In the files of the department there has been accumulated a mass of information relative to other sections of the Borough, such as general locations of pipes and conduit lines, private tunnels, test-pit records and construc-

tion drawings. This information will be used when the final surveys of these sections are taken up.

Similar departments have been established in the other boroughs of the Greater City, using the Brooklyn methods as a basis of operation.

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